LBNL-48242

ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Multi-Project Baselines for Evaluation of Industrial Energy-Efficiency and Electric Power Projects

Jayant Sathaye, Lynn Price, Ernst Worrell, and Michael Ruth
LBNL

Roberto Schaeffer and Márcio Macedo Costa
COPPE, Federal University of Rio de Janeiro

Yanjia Wang
Tsinghua University

Joyashree Roy and Sarmistha Das
Jadavpur University,

Harald Winkler, Randall Spalding-Fecher, Yaw Afrane-Okese, Ogunlade Davidson
University of Cape Town

Environmental Energy Technologies Division

December 2001

This work was supported by the Assistant Secretary of Energy Efficiency and Renewable Energy of the U.S. Department of Energy, and the Climate Protection Division, Office of Air and Radiation, U.S. Environmental Protection Agency through the U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

LBNL-48242

Multi-Project Baselines for Evaluation of

Industrial Energy-Efficiency and Electric Power Projects

Jayant Sathaye, Lynn Price, Ernst Worrell, and Michael Ruth
Energy Analysis Department
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory
Berkeley, CA 94720 USA

Prepared for the U.S. Environmental Protection Agency
Market Policy Branch
Clean Air Markets Division
Office of Atmospheric Programs
Washington, DC

Maurice LeFranc, Project Manager

2001

This work was supported by the U.S. Environmental Protection Agency through the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

Multi-Project Baselines for Evaluation of Industrial Energy-Efficiency and Electric Power Projects

Table of Contents

LBNL-48242

Multi-Project Baselines for Evaluation of Industrial Energy-Efficiency and Electric Power Projects

Jayant Sathaye, Lynn Price, Ernst Worrell, Michael Ruth
Lawrence Berkeley National Laboratory

2001

Multi-Project Baselines For Evaluation Of Industrial Energy-Efficiency And Electric Power Projects

Table of Contents

LBNL-48242

Multi-Project Baselines for Evaluation of Industrial Energy-Efficiency and Electric Power Projects

Jayant Sathaye, Lynn Price, Ernst Worrell, Michael Ruth
Lawrence Berkeley National Laboratory

Roberto Schaeffer and Marcio Macedo Costa
Federal University of Rio de Janeiro

Wang Yanjia
US/China Energy and Environment Technology Center, Tsinghua University, Beijing

Joyashree Roy and Sharmistha Das
Jadavpur University, Calcutta

Harald Winkler, Randall Spalding-Fecher, Y. Afrane-Okese, Ogunlade Davidson
Energy Development Research Center, University of Cape Town

December 2001

Multi-Project Baselines for Evaluation of Industrial Energy-Efficiency and Electric Power Projects

Jayant Sathaye, Lynn Price, Ernst Worrell, Michael Ruth
Lawrence Berkeley National Laboratory

Abstract

Calculating greenhouse gas emissions reductions from projects requires construction of a hypothetical baseline that approximates emissions levels without the project. This paper describes a standardized multi-project baseline methodology for industrial energy-efficiency and electric power projects. The multi-project baseline methodology is illustrated with four case studies. Two case studies, for Brazil and China, focus on energy-efficiency projects in the cement sector. The other two case studies focus on electric power sector projects in India and South Africa. From the four case studies, it is clear that the most difficult aspect of setting multi-project baselines is determining the appropriate criteria in terms of baseline plants, baseline breadth, and baseline stringency in order to balance the desire to encourage no- or low-carbon projects while maintaining environmental integrity. Overall, we found that it is important to fully evaluate the variety of potential baselines in order to make informed decisions regarding which plants to include in the baseline, what type of baseline to use, and what level of stringency to use. Further research is required to fully understand the ramifications of the various choices in constructing and using these baselines.

Keywords: baselines, industrial energy efficiency, electric power, greenhouse gas emissions, climate change projects, case studies

1. Introduction

Calculating greenhouse gas (GHG) emissions reductions from projects requires construction of a hypothetical baseline that approximates emissions levels without the project. Such baselines can be project-specific, multi-project, or a hybrid of the two (Ellis and Bosi, 1999). Project-specific baselines are determined on a project-by-project basis using specific measurements or assumptions. Multi-project baselines use existing or estimated emissions levels from a defined set of actual or projected projects to derive a baseline level. The hybrid approach combines project-specific and standardized parameters to derive a baseline (Ellis and Bosi, 1999).

This paper describes a standardized multi-project baseline methodology for industrial energy-efficiency and electric power projects. For the purposes of this paper, we assume that the proposed projects have already passed an additionality test and have been accepted as qualified projects. Additionality tests are designed to ensure that a proposed project will result in actual GHG emissions reductions that would not have occurred in the absence of the project. The multi-project baselines described in this paper are then used for estimating the number of carbon emission reduction (CER) units that is earned from a project. The multi-project baseline methodology is illustrated with four case studies. Two case studies, for Brazil and China, focus on energy-efficiency projects in the cement sector. The other two case studies focus on electric power sector projects in India and South Africa.

2. Rationale for Use of Multi-Project Baselines

The rationale for exploring the use of multi-project baselines as an alternative to project-specific baselines is to seek a balance between ensuring environmental integrity and minimizing transaction costs while encouraging emissions reduction projects. Project-by-project baselines may have higher transaction costs than multi-project baselines, reducing the number of projects that attract investment. Experience with other project evaluations has shown that construction of project-specific baselines is time-consuming, costly, and can be highly uncertain[1]. Thus, the concept of standardized baselines across many projects, for particular sectors or given technologies, has emerged. These multi-project baselines can be used as an alternative to project-specific baselines depending upon the preference of the developer and/or the host country government. The aim of this paper is to explore alternative options for multi-project baselines.

Project-specific baselines can be static or dynamic. Static baselines are set at the time of project approval and remain unchanged for the duration of the project, while dynamic baselines may be revised during the course of the project should new information about the baseline conditions require a re-examination of the original baseline. Multi-project baselines too could be adjusted in a similar manner if the original baseline were to undergo an unexpected change.

[1] Specifically, projects related to the Activities Implemented Jointly (AIJ) pilot phase were initiated at the first United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties to test the impact of implementing emissions reductions projects in some countries (developing countries or countries with economies in transition). An evaluation of a number World Bank-managed Prototype Carbon Fund projects found that the costs associated with preparing a project-specific baseline study and presenting a case for environmental additionality are about US$20,000 per project (World Bank, 2000). Uncertainty related to calculation of emissions reductions using project-specific baselines has been estimated to range from ± 35% to ±60% for demand-side, heat supply, cogeneration, and electricity supply projects (Parkinson et al., 2001).

Establishing a baseline for a particular activity, sector and/or region potentially simplifies the calculation of emissions reductions. Baselines need to be simple enough to be practical in developing countries.

Three key decisions[2] are required to calculate multi-project baselines:

Choosing Baseline Plants: The first decision is which set of plants to include in the multi-project baseline. For each plant, the essential data are the fuel input (in GJ per year) and the product output (in tonnes/year for industrial projects) or electrical output (in TWh/year for power projects). Combining this information with the calorific value of the fuel and its carbon content, we can calculate the carbon (C) intensity. The carbon intensity is measured in mass of carbon per unit of product output or energy produced, e.g. in units of kg C/tonne or kg C/kWh. This carbon intensity value is the key element for constructing the emissions baselines. Once the multi-project baselines are constructed using the calculated carbon intensity levels, project CERs are determined by multiplying the difference between the project's carbon intensity level and that of the chosen baseline level by the project's annual production.

One approach for constructing multi-project baselines is to use carbon intensity values for recently-constructed plants to calculate the baseline, assuming that these represent the best available technology. An advantage of this approach is that the data for such plants are observable. Another approach is to use a "forward-looking" baseline that includes near-future plants, making assumptions about which plants would most likely be built. A forward-looking baseline has the advantage that it can consider new, more efficient technologies. Arguably this type of baseline is more realistic regarding what new technologies are likely to be used. In this sense, a "forward-looking" baseline is likely to be methodologically more accurate while one based on "recently-constructed" units is likely to have more accurate data.

A concern is that forward-looking baselines are open to "gaming" in which countries have an incentive to choose a baseline with high carbon intensity, so that projects will be able to earn more credits. Gaming can be avoided to some extent by including factors that are difficult to change, for example requiring the projection to be based on published government or utility plans. Setting regional baselines also makes gaming more difficult, as would a system of international review (Meyers, 2000). To the extent that gaming cannot be avoided, there is a trade-off between this risk and the risk of free riders against a backward-looking baseline that does not promote the best available technology.

Fuel-switching is a complicating issue regarding the choice of either recently-built or forward-looking baselines. If lower-carbon fuels are available and have not yet been fully utilized, then a baseline using recently-built, more carbon-intensive, plants or a forward-looking baseline that captures this opportunity could provide larger emissions credits for lower carbon projects. Also, if the current trend in the country is to fuel-switch away from lower carbon fuels and future plans reflect this trend, then a recently-built baseline could also be the best choice in terms of providing larger credits for lower-carbon projects.

Choosing Baseline Breadth: The second issue is which set of plants should be used for comparison to the proposed project. For example, does a proposed gas plant need to perform better than the average power station in the whole sector, the average fossil-fueled plant or better than other gas-fired plants? Obviously, the fuel-specific comparison only works if there is at least

[2] These three decisions are analyzed here. Lazarus et al. (1999) note another methodological issue – the degree of aggregation, which we do not address.

one plant or unit in the baseline using the same fuel as the project. The decision whether to compare the proposed project to other plants using the same fuel ("fuel-specific"), to all fossil fuel-fired plants ("all fossil"), or to the entire sector ("sector-wide") will need to be made based on country-specific conditions. The choice of an appropriate baseline may also be technology specific. Thus for a proposed coal project one might use a mix of baseload plants, while a mix of peaking units (plants that are only operated during peak demand periods) might be a more appropriate multi-project baseline for a solar PV unit.

Choosing Baseline Stringency: The third decision to make when constructing multi-project baselines is whether to compare potential projects against average, better-than-average or best plants. Once the carbon intensity of the baseline plants is calculated, increasingly stringent benchmarks can be constructed: average, weighted average, 25th percentile, 10th percentile, or best plant. The choice of stringency level will determine the amount of CERs a project will earn by comparing the actual performance of the project to the chosen multi-project baseline level. The choice of this stringency level will need to balance the desire to encourage GHG emissions reduction projects with the desire ensure that CERs are only granted for additional emissions reductions.

In addition to being used to determine CERs, multi-project baselines can also be used to test for additionality. Additionality raises the question of whether a proposed project would have been undertaken as part of the baseline activity anyway. Institutional, financial, and technological additionality tests in order to check for environmental additionality have been proposed. A financial test would check to see whether a proposed project meets investment criteria when carbon benefits are included, but not otherwise. Institutional additionality requires the establishment of new institutions. Technological additionality is the demonstration of new technology that is specific to the proposed project. Multi-project baselines can also provide an indication of whether a project appears to be additional by comparing the proposed project to one of the more stringent benchmarks, such as best plant or the 10th percentile level. Projects that perform better than these stringent levels could be assumed to result in GHG emissions reductions that would not have otherwise occurred.

3. Multi-Project Baselines for Evaluation of Industrial Energy-Efficiency Projects

The industrial sector clearly dominates global total primary energy use, using an estimated 130.8 EJ, or over 40%, in 1995 (Price et al., 1998). Carbon dioxide (CO_2) emissions associated with this energy use were 2370 MtC, about 43% of global CO_2 emissions from energy use (Price et al. 1999). The largest growth in industry-related CO_2 emissions has been seen in developing countries as these countries construct roads, buildings, and other infrastructure-related structures that require large amounts of energy-intensive industrial commodities such as steel, aluminum, and cement (Price et al., 1999).

LBNL has developed a "process-step" multi-project baseline methodology for energy-intensive industrial sectors in which the important energy-consuming production steps in an industry are assigned a value based on actual performance of existing plants. In this section, we explain the use of this methodology in the cement sector and present two case studies in which five baseline energy-consumption levels (average, weighted average, 25th percentile, 10th percentile, and best plant) are tested.

Process-Step Multi-Project Baselines for Cement Energy-Efficiency Projects[3]

Almost 3% of global energy-related CO_2 emissions and over 6% of global industrial energy-related CO_2 emissions are from the manufacture of cement. In addition, cement manufacture also contributes an almost equal amount of CO_2 from process emissions due to the calcining process (see below) (Hendricks et al., 1999). Global cement production grew at a rapid rate of 3.6% per year between 1971 and 1995, dominated by growth in developing countries (Hendricks et al., 1999).

Cement production is an energy-intensive process in which a combination of raw materials is chemically altered through intense heat to form a compound with binding properties. The main steps in cement production are illustrated in Figure 1.

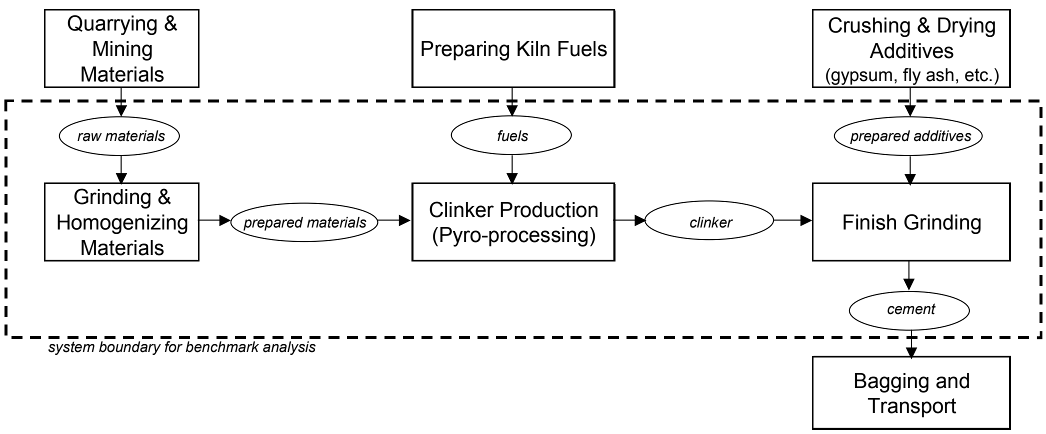

Figure 1: The Cement Production Process

Raw materials, including limestone, chalk, and clay, are mined or quarried, usually at a site close to the cement mill. These materials are then ground to a fine powder in the proper proportions needed for the cement. These can be ground as a dry mixture or combined with water to form a slurry. The addition of water at this stage has important implications for the production process and for the energy demands during production. Production is often categorized as dry process and wet process. Additionally, equipment can be added to remove some water from the slurry after grinding; the process is then called semi-wet or semi-dry.

This mixture of raw materials enters the clinker production (or pyro-processing) stage. During this stage the mixture is passed through a kiln (and possibly a preheater system) and exposed to increasingly intense heat, up to 1400 degrees Celcius. This process drives off all moisture, dissociates CO_2 from calcium carbonate, and transforms the raw materials into new compounds. The output from this process, called clinker, must be cooled rapidly to prevent further chemical changes. Finally the clinker is blended with certain additives and ground into a fine powder to make cement. Following this cement grinding step, the cement is bagged and transported for sale, or transported in bulk.

In cement making, about half of the carbon dioxide emissions result from energy use and the other half are from the decomposition of calcium carbonate during clinker production (calcining) (Hendriks, et al., 1999). The most energy-intensive stage of the cement production process is clinker production, which accounts for up to 90 percent of the total energy use. The grinding of

[3] Based on Ruth et al., 2000.

raw materials and of the cement mixture both are electricity-intensive steps and account for much of the remaining energy use in cement production. Because these three steps are the most energy-intensive and have seen the most technological advancements over time, they are the process steps used for setting the multi-project baselines, as shown by the system boundary in Figure 1.

Setting this system boundary in an important step. The most energy-intensive steps should be included inside the benchmark, while steps that do not now consume much energy or which have extremely difficult or inconsistent data requirements can be left outside the boundary. For our evaluation, we include the three steps indicated in the diagram and evaluate electricity use at the grinding stages and combustible fuel use in the clinker production stage.[4]

To establish an evaluation tool for cement production that addresses the three stages identified above and uses a benchmarking approach, it is necessary to establish benchmark performance values for each of the three stages. Then a project can be compared against the benchmark to determine the projected level of carbon dioxide reduction the project will accomplish.

The formula for calculating carbon emission reductions at a cement plant is given below. This formula takes into account only energy use at the three key process stages: raw material preparation, clinker production, and cement grinding. A benchmark value is used at each stage to measure the carbon emissions avoided.

$$C(t) = \sum_f m_f q_f \cdot \underbrace{\left(b_K \cdot X_K(t) - K(t)\right)}_{\text{clinker production}} + q_e \cdot \left[\underbrace{\left(b_M \cdot X_M(t) - M(t)\right)}_{\text{raw materials}} + \underbrace{\left(b_G \cdot X_G(t) - G(t)\right)}_{\text{cement grinding}}\right] \quad (1)$$

$C(t)$ = carbon dioxide emission reduction at the plant in year t (tonnes CO_2)
Carbon contents:
m_f = percentage of fuel f in total primary fuel use for year t (%)
q_f = carbon content of fuel f (tonnes CO_2/GJ)
q_e = carbon content of electricity (tonnes CO_2/kWh)
Outputs:
$X_M(t)$ = output of raw material at the plant in year t (tonnes)
$X_K(t)$ = output of clinker at the plant in year t (tonnes)
$X_G(t)$ = output of ground cement at the plant in year t (tonnes)
Energy Use:
$M(t)$ = total plant electricity use for raw materials preparation in year t (kWh)
$K(t)$ = total plant energy use for clinker production in year t (GJ)
$G(t)$ = total plant electricity use for cement grinding in year t (kWh)
Benchmarks:
b_M = energy benchmark for raw material production (kWh/tonne raw material)
b_K = energy benchmark for clinker production (GJ/tonne clinker)
b_G = energy benchmark for cement production (kWh/tonne cement)

In the cement production process, CO_2 emissions can be grouped as "energy-related", referring to emissions that result from the combustion of fossil fuel, and "process-related", referring to the emissions from the decomposition of calcium carbonate. Process-related emissions are not

[4] A more detailed or comprehensive analysis may yield a different analysis boundary. For example, if more detail is desired, the use of electricity to rotate the kiln could be included. Also, if projects that introduce a greater proportion of additives in cement are included in the analysis, the additive preparation step could be included. Our boundary is intended as an illustrative example.

accounted for in Equation (1) because they are not a matter of efficiency or performance; instead they are related to the total amount of clinker produced and not to the technology used. These emissions can be reduced on a per tonne of cement basis by decreasing the amount of clinker per tonne of cement (the clinker-to-cement ratio). This is referred to as "blended cement". This aspect has been left out of Equation (1) because it presents some difficult issues. For now, the calculation is neutral to the clinker-to-cement ratio.

Determining the value to assign as benchmarks for the above equation is not a simple task. Cement production is highly competitive and efficient equipment is the norm. It is plausible to consider setting benchmarks for the cement process steps from: (1) average annual performance data from individual plants across the industry, (2) actual performance data from recently constructed plants, or (3) documented best technology information. While the first of these options would allow us to generate a trend of energy performance at newly added facilities over time, and therefore might indicate a future trend for plants, data availability may make this a difficult approach. Following this approach requires performance data at each process step for each plant in a country, as well as information on the vintage or age of each component. This may be difficult to obtain. Furthermore, there may not be enough plants built in a given region, or the plants in a region may be too old, for a reasonable trend to be observed.

It is easier to compile a reliable dataset for the other two options. For example, when new plants are constructed, the manufacturer often gives a "guaranteed" value for the performance of the kiln, and the manufacturer will compensate the facility owner if the value is not met. Thus, actual performance data from recent plants may be available because plant owners are monitoring actual kiln production compared to guaranteed values. Documentation on the best available technologies for all processes is obtainable from cement associations, such as Cembureau, the European Cement Association, and may be the most simple method for establishing benchmark values.

3.2. Case Studies

Energy analysts at the Federal University of Rio de Janeiro, Brazil and Tsinghua University, China worked with LBNL staff to test the process-step multi-project baseline approach using data on cement production from each country. Descriptions of the cement industry and the results of the country-specific evaluations of the methodology provided below are excerpted from the individual reports (Schaeffer and Costa, 2001; Wang, 2001).

3.2.1 Brazil[5]

Cement production has grown steadily in Brazil in the past three decades. Just five years ago, in 1995, Brazil was the thirteenth largest cement producer in the world (SNIC, 1996). In 1996, the country was already the eighth largest producer, the seventh in 1997 and the sixth in 1998 (SNIC, 1999). In 1998, the country had a total production/consumption of 40 Mt of cement (or 250 t of cement/capita), out of a world production of 1,536 Mt of cement (SNIC, 1999). That year, 41 different companies, with 59 producing plants (with 11 grinding-only plants), were in operation in Brazil.

Due to its extremely high energy intensity and large volumes of production involved, cement manufacture in Brazil accounted for 7%, 4% and 5% of total energy use in the industrial sector in 1970, 1995 and 1999, respectively. In terms of carbon emissions from energy use, cement manufacture accounted for 7% of total industrial emissions in the country in 1994 (MME, 2000).

[5] Based on Schaeffer and Costa, 2001.

In this study, baselines are set using data for fourteen relatively new cement plants in the country, five of which are oil-fueled, four are coal-fueled and five are multi-fueled.[6] The main criterion used for choosing these plants was to build a baseline composed only of highly energy-efficient clinker production units. These fourteen plants are the most recently built and the most modern plants in operation in the country today. A baseline that included plants under construction or planned plants is not considered because such information is currently not available in Brazil.

Baselines for the raw material production and the cement grinding stages require information on electricity consumption on a plant-by-plant level. However, such information is not currently available in Brazil and estimated values of 26 kWh/tonne (0.12 kgC/tonne) for raw material production and 42.6 kWh/tonne (0.2 kgC/tonne) for cement grinding were used for setting the baselines for these two process steps. These estimates are based on total electricity consumption, 116 kWh/tonne cement, in the Brazilian cement sector in 1995, applying shares for each step in typical portland cement plants in Brazil (dry process). However, carbon emissions derived from electricity generation are extremely low in Brazil due to the fact that about 95% of all electricity generated and consumed in the country has a hydroelectric origin. Thus, electricity savings technologies are not considered in this study and the estimates for electricity consumption are illustrative only.

Table 1 provides the carbon intensity multi-project baseline levels for the fourteen recently-built cement plants in Brazil. The carbon intensities are given for sector-wide and fuel-specific baselines. Table 2 presents information on six hypothetical energy-efficiency cement projects. Project 1 refers to a plant using 100% fuel oil with the "best plant" specific energy consumption (SEC) of 3.09 GJ/tonne clinker and carbon intensity of 65.16 kg C/tonne clinker, both for clinker production only. Projects 2 to 4 refer to plants with the "best plant" SECs of 3.09 GJ/t clinker and using 100% of a different fuel each (natural gas, charcoal and bagasse). These plants have carbon intensities of 47.26 kg C/tonne, 29.96 kg C/tonne, and 0.0 kg C/tonne, respectively. Projects 5 and 6 refer to plants using 100% coal and 100% natural gas, respectively, both with SECs of 3.15 GJ/t clinker. The carbon intensities of these two plants are 81.27 kg C/tonne and 48.20 kg C/tonne, respectively.

When compared to the sector-wide baseline, only the two renewable energy projects (3 and 4) have carbon intensities below the best plant baseline level (see Figure 2)[7]. The two natural gas projects (2 and 6) fall between the 10^{th} and 25^{th} percentiles, the fuel oil project (1) falls below the average baseline value and the coal plant (5) exceeds all baseline carbon intensity values.

[6] The multi-project baseline energy and carbon (from energy use only) intensities of cement manufacture are based on data from 1995, the last year for which information on fuel energy consumption is available on a plant-by-plant basis.

[7] Figure based on Ellis, 2000.

Table 1. Multi-project carbon intensity baseline levels for three cement processes based on fourteen recently-built cement plants in Brazil (kg C/tonne)

	Average	Weighted Average	25th Percentile	10th Percentile	Best Plant
Raw Material Grinding	0.12	0.12	0.12	0.12	0.12
Clinker Production: sector-wide	69.90	71.56	55.25	44.27	31.73
Clinker Production: fuel-specific (coal)	84.31	83.22	79.69	79.69	79.69
Clinker Production: fuel-specific (fuel oil)	69.56	69.53	67.46	67.33	67.33
Cement Grinding	0.20	0.20	0.20	0.20	0.20
Total (sector-wide)	70.22	71.88	55.57	44.59	32.05
Total (coal)	84.63	83.54	80.01	80.01	80.01
Total (fuel oil)	69.88	69.85	67.78	67.65	67.65

Table 2. Six hypothetical energy-efficiency cement projects in Brazil

		Project 1	Project 2	Project 3	Project 4	Project 5	Project 6
Fuel		Fuel oil	Natural gas	Charcoal	Bagasse	Coal	Natural gas
Capacity	tonne clinker/day	1800	3000	3000	3000	4000	4000
Raw Material Grinding							
Energy intensity	kWh/tonne	26.00	26.00	26.00	26.00	26.00	26.00
Carbon intensity	kg C/tonne	0.12	0.12	0.12	0.12	0.12	0.12
Clinker Production							
Energy intensity	GJ/tonne	3.09	3.09	3.09	3.09	3.15	3.15
Carbon intensity	kg C/tonne	65.16	47.26	29.96	0.0	81.27	48.20
Cement Grinding							
Energy intensity	kWh/tonne	42.59	42.59	42.59	42.59	42.59	42.59
Carbon intensity	kg C/tonne	0.20	0.20	0.20	0.20	0.20	0.20
Total							
Energy intensity	kWh/tonne	71.68	71.68	71.68	71.68	71.74	71.74
Carbon intensity	kg C/tonne	65.48	47.58	30.28	0.32	81.59	48.52

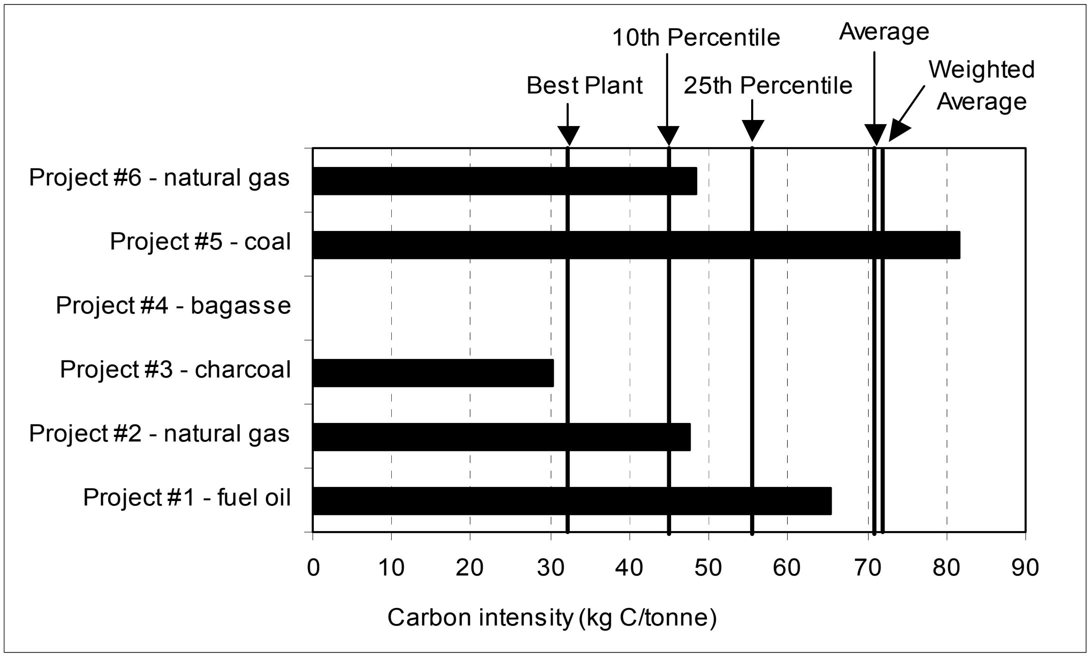

Figure 2. Carbon intensity of six hypothetical energy-efficiency cement projects in Brazil compared to the multi-project sector-wide baseline

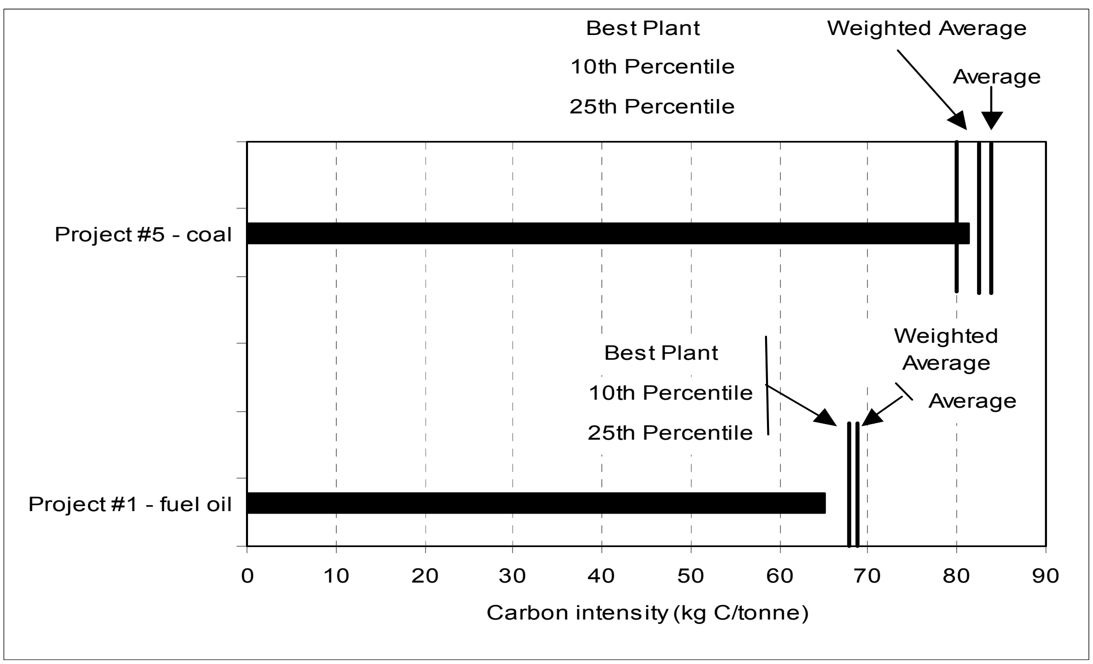

Figure 3. Carbon intensity of two hypothetical energy-efficiency cement projects in Brazil compared to the fuel-specific baselines (Project 1 compared to fuel oil; Project 5 compared to coal)

Along with being compared to baselines calculated based on all fuels used in the sector, energy-efficiency projects can also be compared to fuel-specific baselines. In this case, the two fuel-specific baselines are for projects 1 (fuel oil) and 5 (coal) (see Figure 3). The carbon intensity of project 1 is lower than all the fuel-specific baseline values, including that for the best plant, because the plant's specific energy consumption (3.09 MJ/kg clinker) is equal to the SEC of the most efficient cement plant in Brazil and is thus lower than the SEC of any other fuel-oil cement plant. Only when evaluated using an all-fuel baseline is it obvious that project 1 (as shown in Figure 2), despite its high level of energy efficiency, cannot compete in terms of carbon emissions with less energy-efficient cement plants fueled with natural gas, charcoal, and bagasse. The carbon intensity of project 5, on the other hand, is lower than the average and weighted average baseline values of the coal-specific baseline, but exceeds the other three baseline values (Figure 3).

3.2.2. China[8]

China's first cement plant was built in 1889. Growth in cement production has been very fast, especially during the last two decades. In 1985, China became the largest cement producer in the world. Now China's cement output accounts for more than one third of total cement production worldwide.

Cement production in China grew at an average rate of about 10% from 1980 to 1999, slightly higher than that of the gross domestic product (GDP) (about 9.4%). Because of the high demand for cement, many small-scale cement plants were built through township and village enterprises. At the end of 1997, there were 8435 cement plants with a total capacity of 660 million tons of clinker per year. There were only 576 large-scale plants with an annual output larger than 200,000 tons each. To date, China only has 17 kilns with a capacity larger than 3000 tons of clinker per day.

In general, the energy intensity of cement manufacturing in China is much higher than in developed countries. Coal is the only fuel used in cement kilns in China. Because coal-fired power plants generate almost four-fifths of total electricity in China, the carbon intensity for cement production is much higher than other countries.

During the past two decades, supported by domestic commercial banks, the Asian Development Bank, the World Bank, and other financial sources, some cement plants have introduced advanced technologies and equipment to retrofit their plants. Even so, most of the plants kept their old kilns for production because cement demand was high. Thus, these cement plants have two or three generations of kilns that include wet process kilns, vertical kilns, and new suspension preheater/precalciners (NSP).[9]

For this analysis, data were collected for six of the newest generation of kilns from six cement plants. These kilns have run steadily for several years and represent the present advanced technology of the cement industry in China. These plants are located nation-wide. They consume various kinds of coal and electricity from different power grids. There are eight independent power grids in China and some grids include more hydropower than others. In order to simplify the multi-project baseline calculation, the national-level fuel mix for electricity generation was

[8] Based on Wang, 2001.
[9] NSP kilns are the most efficient kilns and have both suspension preheaters and precalciners.

used to calculate the carbon content of electricity for this analysis. The electricity carbon content in China is much higher than those countries that use more hydro and low carbon content fossil fuel such as natural gas and fuel oil for power generation, since China's electricity sector is based primarily on the use of fossil fuel (82.4%) with a smaller contribution of hydro (16.4%) and nuclear power (1.2%) (Fridley et al., 2001).

Table 3. Multi-project carbon intensity baseline levels for three cement processes based on six recently-built cement kilns in China (kg C/tonne)

	Average	Weighted Average	25th Percentile	10th Percentile	Best Plant
Raw Material Grinding	15.76	15.71	15.17	15.07	15.07
Clinker Production	87.47	85.92	79.22	78.22	78.22
Cement Grinding	8.78	8.72	7.36	7.33	7.33
Total	112.01	110.35	101.75	100.62	100.62

Table 3 provides the carbon intensity multi-project baseline levels for the six cement kilns. All the values apply to all three types of baselines (sector-wide, all-fossil, and fuel-specific) because Chinese cement kilns use coal exclusively. Table 4 presents information on five hypothetical cement projects. Project 1 is based on the use of advanced domestic technology using coal as the main fuel. Project 2 also uses coal, but is based on imported technology and has a larger capacity. Project 3 uses energy-efficient technology for the grinding stages and uses coal for the clinker production. Project 4 is based on imported technology using a mix of 50% coal and 50% natural gas. Finally, Project 5 relies on imported technology using exclusively natural gas as a fuel.

Present domestic advanced technology, as represented by Project 1, is only better than the average and weighted average benchmarks (see Figure 4). Domestic advanced technology with additional electricity-efficiency improvements, as represented by Project 3, is better than all of the benchmarks from a total plant point of view, although the carbon reduction of clinker production is lower than the better-than-average benchmarks. This means that electricity efficiency is an important reduction measure because of the reliance on coal as the main source for power generation. This conclusion is made based on the nation-wide power source mix; for some areas where more hydropower is used for electricity production, there may be no carbon reduction benefits through electricity-efficiency improvement.

Imported advanced technology using coal as a fuel source, as represented by Project 2, is better than all of the benchmarks due to the improved energy efficiency in all three process stages. Fuel switching away from coal, as represented by Project 4 (50% coal and 50% natural gas) and Project 5 (100% natural gas), gives the largest carbon emissions reductions.

Only the first three projects can be compared to a fuel-specific baseline, in this case coal. All three of these projects have lower carbon intensities than the average and weighted average fuel-specific baselines. Project 1, which represents present domestic advanced technology using coal as the primary fuel, has a higher carbon intensity than the 25th percentile, 10th percentile, and best plant baselines. Projects 2 and 3, which are based on imported and energy-efficient domestic technologies, respectively, both have lower carbon intensities than the 25th percentile, 10th percentile, and best plant baselines.

Table 4. Five hypothetical energy-efficiency cement projects in China

		Project 1	Project 2	Project 3	Project 4	Project 5
Technology		Advanced domestic	Imported	Domestic energy-efficient	Imported	Imported
Fuel		Coal	Coal	Coal	50% coal 50% natural gas	Natural gas
Capacity	tonne/day	4000	7200	4000	7200	7200
Raw Material Grinding						
Energy intensity	kWh/tonne	64.00	46.00	46.10	46.00	46.00
Carbon intensity	kg C/tonne	14.46	10.40	10.42	10.40	10.40
Clinker Production						
Energy intensity	GJ/tonne	3.13	3.00	3.13	3.00	3.00
Carbon intensity	kg C/tonne	80.75	77.40	80.75	61.65	45.90
Cement Grinding						
Energy intensity	kWh/tonne	35.00	30.00	30.10	30.00	30.00
Carbon intensity	kg C/tonne	7.91	6.78	6.80	6.78	6.78
Total						
Energy intensity	kWh/tonne	102.13	79.00	79.33	79.00	79.00
Carbon intensity	kg C/tonne	103.12	94.58	97.97	78.83	63.08

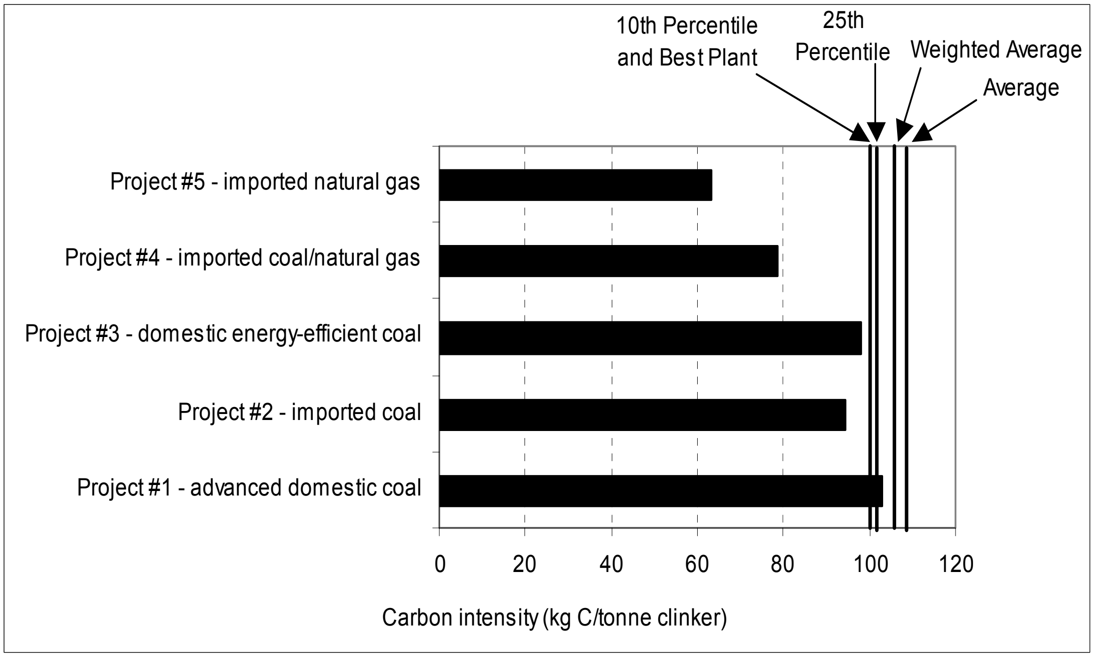

Figure 4. Carbon intensity of five hypothetical energy-efficiency cement projects in China compared to the multi-project sector-wide baseline

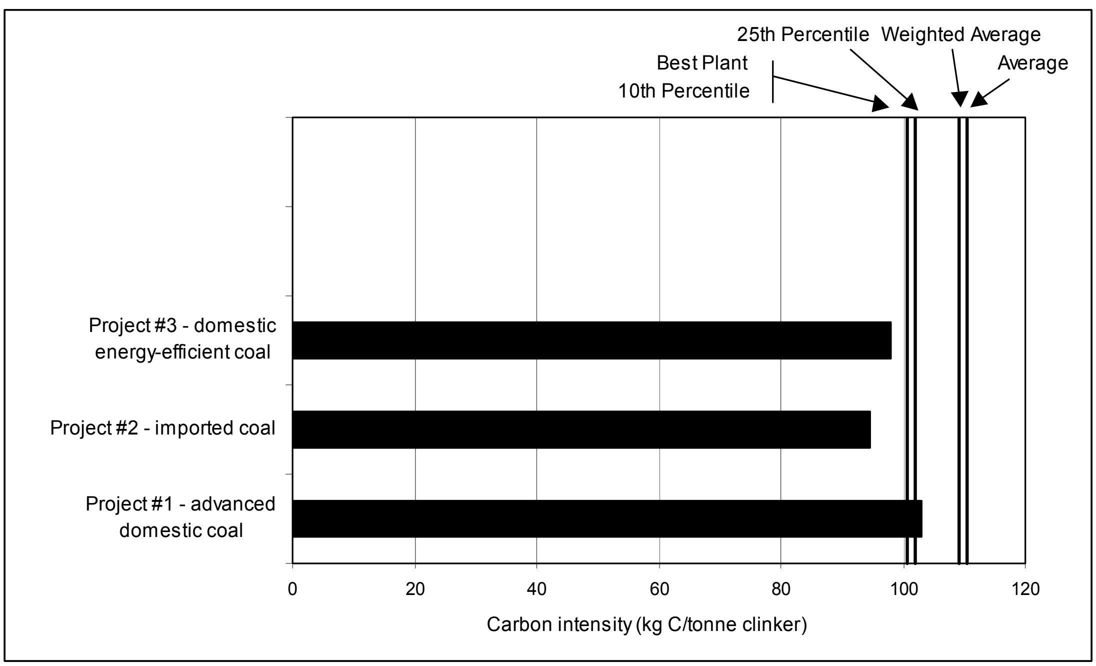

Figure 5. Carbon intensity of three hypothetical energy-efficiency cement projects in China compared to the fuel-specific baseline for coal

4. Multi-Project Baselines for Evaluation of Electric Power Projects

In 1995, global electricity generation was 13,200 TWh and accounted for carbon dioxide emissions of over 2 GtC, or about one-third of global CO_2 emissions (IEA, 1998). Coal is clearly the primary fuel for electricity generation. In 1995, coal represented 44% of the fuel input for generating electricity and was responsible for 70% of electricity-related carbon dioxide emissions (IEA, 1998). Electricity is also generated using oil, natural gas, nuclear power, hydroelectric power, and various renewable energy sources.

LBNL has developed a standardized method for establishing a multi-project baseline for a power system. In this section, we explain the use of this methodology and present two case studies in which five baseline carbon intensity levels (average, weighted average, 25th percentile, 10th percentile, and best plant) are tested.

4.1 Calculating Multi-Project Baselines for Electric Power Projects

Multi-project baselines for electric power projects can be calculated based on recently constructed or planned electric generation facilities in a country. Estimation of the CO_2 emissions that are avoided by projects that supply electricity to the grid requires a baseline that represents what would have happened in the absence of the project. Estimating the effect of projects hinges upon finding the type of power plants whose construction or use would be avoided by the projects, and the carbon emissions avoided by their reduced operation.

Establishing a multi-project baseline for the power system can provide project developers with factors that they could use in calculating the CERs expected from a project and the actual CERS to be claimed after the project is completed. A multi-project baseline based on a mix of planned new capacity or the dominant type of existing capacity and can be expressed in terms of kg C per kWh avoided.

To calculate the baseline, data on annual electricity output (TWh/yr) and annual energy use (GJ/yr) are gathered for each plant in the reference scenario. The carbon intensity of each plant in the reference scenario is calculated by dividing the total annual carbon emissions by annual electricity output:

$$\text{Carbon intensity [tC/MWh]} = \frac{\text{total fossil fuel usage [TJ]} * \text{fuel carbon content [tC/TJ]}}{\text{Annual electricity generation [MWh]}} \quad (2)$$

Country-specific values for the fuel carbon content (or emissions factor) can be used. Alternatively, IPCC values may be used as a default.

4.2 Case Studies

4.2.1 India[10]

The Indian power generation sector uses a wide diversity of energy supply sources including coal, oil, natural gas, hydro, nuclear, wind, solar, and biomass. Coal-based thermal generation dominates the electricity sector in India. Over the last 25 to 30 years, the capacity share of large hydro has declined, while that of nuclear power is growing slowly.

---

[10] Based on Roy and Das, 2001.

Currently, thermal plants account for 72.9% of the total power generation, while hydro and nuclear power plants contribute 15.2% and 2.5%, respectively. The average age of the thermal power stations in India is 30 years. The abundance of coal (India's coal reserve is estimated to be 2000 billion tonnes) coupled with short construction periods of 3 to 4 years for smaller thermal plants with capacity below 250 MW, and between 6 to 7 years for plants above 250 MW capacity have encouraged the dependency on the thermal power in the country. The plant load factor (PLF) is very low in India (average is approximately 65%). Thermal efficiency of the plants varies across plants due to the varying grades of coal used and vintages of plants. The coal use factor ranges from 0.53 kg/kWh to 0.88 kg/kWh. The use of high ash content coal reduces the efficiency of the thermal power plants.

The high dependency of coal implies India's electricity industry has relatively high CO_2 emissions. In addition, some methane (CH4) is released during coal mining, production of coal, and production of natural gas. With 237 million metric tons of carbon released from the consumption and flaring of fossil fuels in 1997, India ranked fifth in total CO_2 emissions in the world behind the United States, China, Russia and Japan (U.S. Energy Information Administration, 1999). Thus, increased power generation in India to satisfy the growing demand for electricity will continue to increase GHG emissions significantly.

For ease of operation of the power system, the electricity distribution network in India is divided into several regions: north, west, south, east and north-eastern region. We focus on the eastern region in this analysis. The eastern region covers three states –West Bengal, Bihar and Orissa. Though public, private, and government-owned public sector undertakings (PSUs)[11] are all engaged in power generation, transmission and distribution, the power industry in this region is dominated by the PSUs. Total installed capacity in this region is 16,973 MW which is 15% of the total installed capacity of the country. Six PSUs in this region own 57% of the total regional power generation capacity, public sector owns 29% and the remaining 14% of generation capacity is owned by the Calcutta Electric Supply Corporation (CESC), the only private licensee in this region. Like other regions, the regional power grid in the eastern region, governed by the Eastern Regional Electricity Board (EREB), facilitates flows of power from surplus areas to deficit areas and assists the optimum utilization of the power available in the country. Total consumption in this region in 1999-2000 was 46,165 megawatt hours (MWh).

Regional electricity generating capacity is based on three primary resources: coal, oil and hydro. The coal reserve of eastern region is the highest (90%) in India. The availability of coal encouraged the establishment of thermal power stations in this region at a greater rate.

By 2000, there were 25 thermal power plants with 44 major units in the eastern region. Besides coal-based power stations, the eastern region also has 15 hydroelectric power stations and four high speed diesel oil (HSDO)-based gas turbines. Capacity expansion in the eastern region is continuing and a large expansion has been planned over the next decade covering tenth and eleventh Five-Year Plan periods starting from 2003. Twenty-five units (including conventional and non conventional fuel based) with total capacity of 4283 MW (25% of the total existing capacity) began operation since 1994. Of these, 81% are thermal with coal as the primary fuel source, 15% (6.5 MW) are hydro and the remainder (1 MW) are renewable sources such as solar and wind to meet the off grid supply. The future expansion plan of the next decade proposes to construct 26 power stations with a total capacity of 24,313 MW.

---

[11] Public sector undertakings are characterised by more than 50% share holding by the government.

Table 5. Multi-project carbon intensity baseline levels for "recent past" electricity plants in India (kg C/kWh)

	Average	Weighted Average	25th Percentile	10th Percentile	Best Plant
All-fossil	0.390	0.345	0.241	0.217	0.217
Sector-wide	0.280	0.341	0.228	0.192	0.000

Table 5 provides the carbon intensity multi-project baseline levels for the "recent past" baseline for all-fossil generation and for sector-wide generation. These include 13 power plants built since 1995. There are no plants that use only one type of fuel. All thermal plants use both coal and oil. Although coal-fired plants use coal as primary fuel, they do keep provision for use of oil as a supplementary fuel for either starting the system or supplement the primary fuel in case of coal supply shortage or availability of coal racks. For hydro, we assume that the carbon intensity is zero. The fossil fuel-specific carbon intensity is identical for the 10th percentile and the best plant because several of the coal units included in the baseline have identical performance. The zero carbon intensity for the sector-wide category reflects the inclusion of hydro and solar energy based power generation that it is zero-emitting.

Table 6. Five hypothetical electricity generation projects in India

		Project 1	Project 2	Project 3	Project 4	Project 5
Fuel		Hydro	Hydro	99% coal 1% oil	99% coal 1% oil	Renewabl e
Capacity	(MW)	1020	1710	1000	500	6
Annual generation	(TWh)	4.468	7.490	6.132	3.504	0.006
Carbon intensity	kg C/kWh	0.000	0.000	0.220	0.220	0.000

Table 6 presents information on five hypothetical power generation projects. Projects 1 and 2 are large hydroelectric plants with capacities of 1020 MW and 1710 MW, respectively. Projects 3 and 4 are planned as private sector and public sector projects with capacities of 500 and 1000 MW, respectively. They have been planned to be more efficient and to use better quality coal and less oil input. Project 5 represents plans under the renewable energy development agency for decentralized off-grid supply of power of 6 MW of generating capacity.

Both hydroelectric projects 1 and 2, and the renewable project 5, clearly perform at the best plant level, better than all of the other baseline levels for either the sector-wide or the all-fossil baselines (see Figures 6 and 7). The thermal plants (projects 3 and 4) perform better than the weighted average and 25th percentile when using either the sector-wide or the all-fossil baseline, but the CO_2 intensity reduction relative to the 25th percentile is greatest when using the all-fossil baseline. Neither of the thermal-based projects reduce CO_2 emissions when the 10th percentile or best plant baseline is used since these include renewable-based projects in the sector-wide baseline and a "best plant" project with a carbon intensity of 0.217 kg C/kWh in the all-fossil baseline.

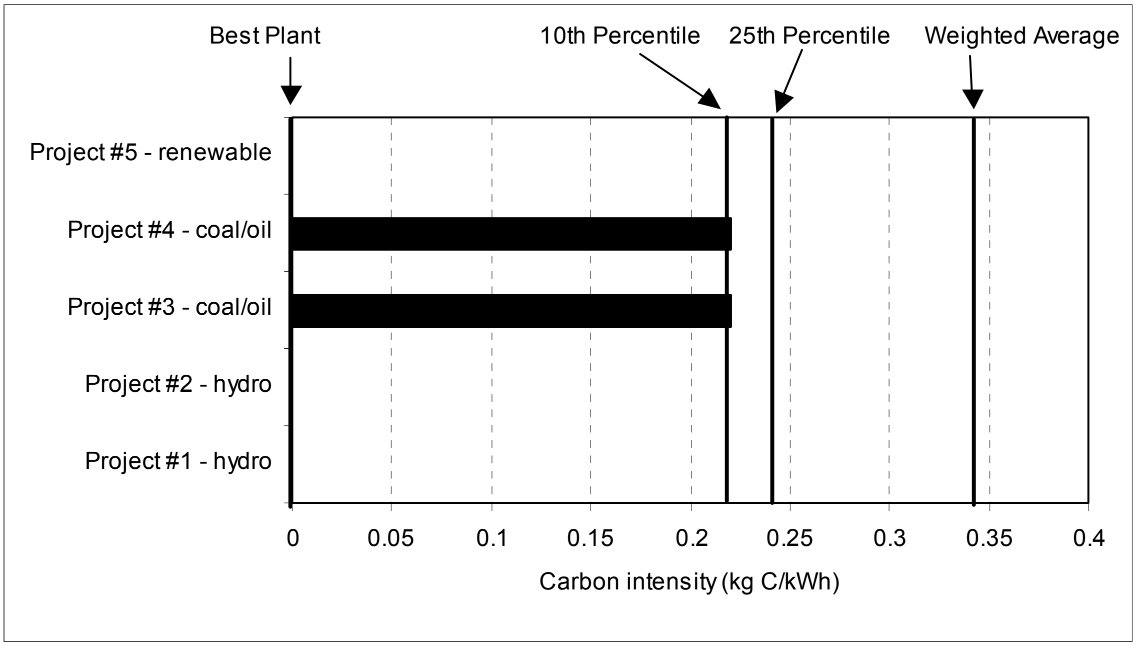

Figure 6. Carbon intensity of five hypothetical electric power projects in India compared to the multi-project sector-wide baselines

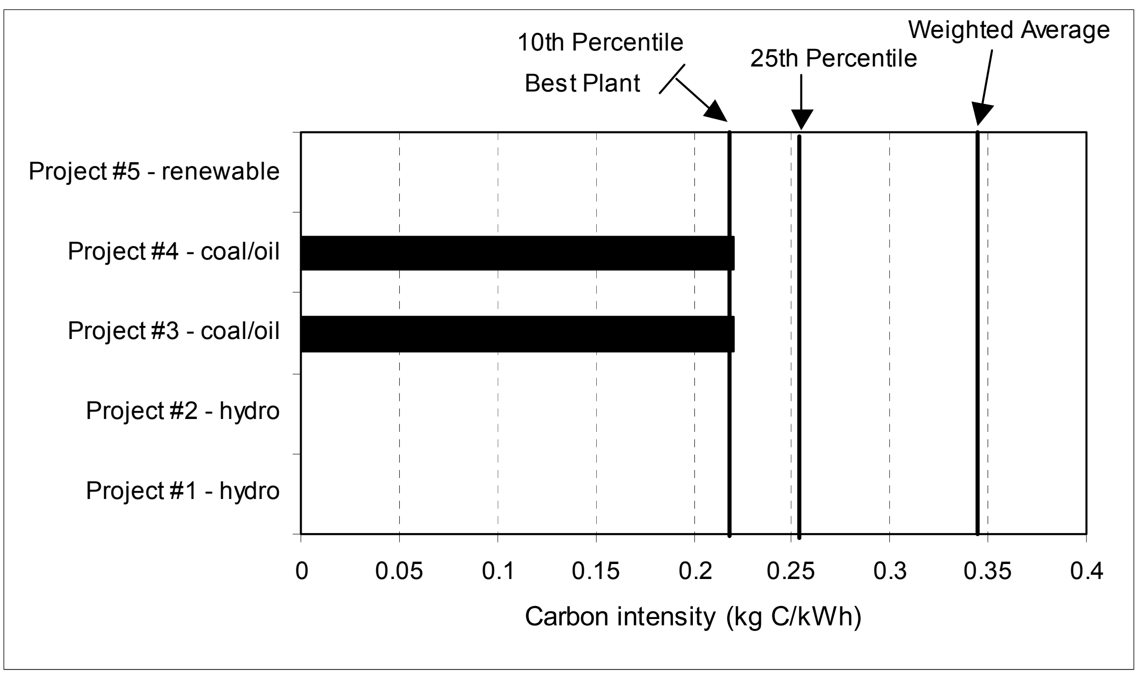

Figure 7. Carbon intensity of five hypothetical electric power projects in India compared to the all-fossil (and fuel-specific) baseline

4.2.2 South Africa[12]

The electricity supply industry in South Africa is almost entirely owned by the public sector – either through the state-owned company, Eskom, or through municipal distributors. Generation and transmission are dominated by Eskom. There are a few self-producers, some of which sell to neighboring communities. Eskom owns 92% of all generation capacity in South Africa, municipalities own 6% and private generators only 2%. The total quantity of electricity generated in South Africa in 1999 was 190 TWh (NER 1999). Eskom accounted for 96% of this total.

South Africa's electricity generating technology is based largely on coal-fired power stations, mostly owned and operated by Eskom and largely concentrated near and to the east of Johannesburg – close to the main coal resources as well as the country's major demand center. At the end of 1999, there were 49 power stations in operation in the country, of which 20 are coal-fired, accounting for 90 per cent of the total capacity of 43,142 MW (excluding capacity in reserve and under construction). Three of Eskom's older coal stations are currently in reserve ("mothballed") because of excess capacity, and these would add an additional 3,556 MW. The only non-coal stations of significance are the Koeberg nuclear power station (4% of operational capacity) and three pumped storage facilities (4% of operational capacity) (NER, 1999). South Africa is known for being one of the world's low-cost producers of electricity. At the beginning of 1997, Eskom, the electric utility had the lowest industrial electricity tariffs in the world. At 2 US cents/kWh, South Africa was followed closely by only New Zealand at 2.5 US cents/kWh (SANEA 1998).

The average age of Eskom's operational power stations is 14 years (weighted by capacity) – this figure is heavily influenced by several large stations constructed in the 1980s. Eskom's coal-fired power stations generally exhibit high thermal efficiencies for conventional pulverised fuel technology. Average efficiencies have consistently been over 34 %, despite the use of low quality (high ash) coal and the use of dry-cooled technology on two newer plants, which is generally slightly less efficient than wet-cooled stations. The weighted average heat content for existing coal-fired power stations is low at 21.3 GJ/t (coal) compared to the IPCC default value of 29.3; carbon content is relatively high at 28.2 tC/TJ compared to the IPCC factor of 25.8 (IPCC 1995). Eskom's moth-balled stations are 30 years old on average and would typically have lower than average thermal efficiencies. The high dependence on coal means that South Africa's electricity industry has relatively high GHG emissions of 159 Mt of CO_2 equivalent in 1998. This is mainly from coal combustion, but includes some methane emissions from coal mines. Overall, South Africa produces 0.96 kg of GHG per kWh produced by coal fired power stations.

Using observed data from recent plants reduces gaming, and is probably desirable for baselines in many electricity sectors. However, in South Africa, deriving baselines based on recently built plants does not work because only one power station, Majuba, has been constructed in the last seven years[13]. At Majuba, four units have been constructed from 1996-1999, and two more are being constructed during 2000 and 2001. If one uses the "recent plant" approach, one therefore compares the proposed projects to the performance of a single power station. The slower growth in demand in South Africa in recent years creates some inertia against changes in the capacity mix (Lazarus 1999). Opportunities to change the capacity mix towards low-carbon technologies are constrained by the existence of excess capacity and moth-balled coal stations. These arguments are specific to the power sector in South Africa, and do not imply that other developing countries might not choose recent plant baselines.

[12] Based on Winkler, et al., 2000.

[13] The last previous plant was Kendal, whose units were commissioned from 1988-1993 (Eskom 1996).

Table 7. Six near future electricity generation projects in South Africa used for development of a near future baseline

		Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6
Fuel		New Coal	New Coal	Moth-balled Coal	Moth-balled Coal	Natural gas	Imported hydro
Capacity	(MW)	713	713	570	870	736	400
Annual generation	(TWh)	3.78	3.78	3.02	4.61	4.13	1.84
Carbon intensity	kg C/kWh	0.295	0.295	0.338	0.338	0.100	0.000

In this analysis, we have therefore chosen a baseline that includes six "near future" plants. Table 7 presents information on these plants, which include the two new units of Majuba, the recommissioning of two units in moth-balled power stations, a new natural gas plant and imported hydroelectric power (Eskom, 1996; Eskom, 1998; Eskom, 1999; NER, 1999). Given the directions set by Eskom's Sixth Integrated Electricity Plan, one could reasonably expect these units to come on line between 2000 and 2005 (Eskom, 1998).

Table 8. Multi-project carbon intensity baseline levels for "recent past" electricity plants in South Africa (kg C/kWh)

	Weighted Average	25th Percentile	10th Percentile	Best Plant
Fuel-specific: coal	0.316	0.295	0.295	0.295
Fuel-specific: natural gas (1 plant only)	0.100	0.100	0.100	0.100
All-fossil	0.270	0.128	0.100	0.100
Sector-wide	0.247	0.065	0.013	0.000

Table 8 provides the multi-project sector-wide, all-fossil, and fuel-specific carbon intensity baseline levels based on "near future" plants. The benchmarks get more stringent from left to right, as expected. However, the coal-specific carbon intensity is identical whether one uses the 25th percentile, 10th percentile or best plant. This is because several of the coal units included in the baseline have identical performance. Natural gas has much lower carbon intensity than coal – and this constitutes the best plant and 10th percentile for the "all fossil" comparison. The zero carbon intensity for the best plant sector-wide reflects the inclusion of imported hydro and the assumption that it is zero-emitting.

For coal-based generation, the baseline generally gets more stringent as one moves from fuel-specific to all fossil and sector-wide comparisons. This is because the all-fossil comparison adds in natural gas, and the sector adds the imported hydro, bringing down the weighted average carbon intensity. Natural gas does not follow this trend since the fuel-specific carbon intensity is lower than the all-fossil or sector-wide intensity, which include more carbon-intensive coal. In this example, the weighted average and percentiles for gas are based on one plant only. While it may be more mathematically correct to base such measures on more than the one gas plant included here, the value of the single plant is included across all baselines since that is what one would compare the project against.

Table 9 presents information on five hypothetical electricity generation projects. Project 1 is based on importing gas from the Kudu Gas fields for three units of 368 MW each (Roggen 2000). New gas-fired power plants are substantially less carbon-intensive than coal-fired plants. Project 2 is based on plans for the Darling wind farm to install 5 MW for production of electricity for the grid (Asamoah 2000). Project 3 is based on the use of more efficient, super-critical coal plants. Project 4 is based on an Eskom initiative to install 18 million compact fluorescent lights (CFLs) to reduce energy demand in the residential sector (Eskom 2000). Rather than increasing supply, this project aims to reduce demand for electricity, and thus avoid emissions. By including an energy efficiency option, it is possible to measure demand- as well as supply-side options against one multi-project baseline. Project 5 is based on Off-grid Solar Home Systems. The aim of the programme to use off-grid solar home systems to electrify rural areas unlikely to receive grid electricity. The project has a target market of 350,000 households (Qase 2000). In comparing this programme to the multi-project baseline, one implicitly assumes that it will displace electricity, whereas it is more likely that paraffin or diesel will be displaced. The difference in emissions reductions is substantial, with a typical 50Wp system displacing around 230 kg CO_2 per system per year when compared to traditional fuel use, but only about 40-80 kg CO_2 per system per year compared to grid electricity (Ybema et al. 2000). Based on international experience, the value for diesel generates would be expected to lie between these two. For this reason, it seems appropriate to use different benchmarks for off-grid projects and grid-connected ones.

Table 9. Five hypothetical electricity generation projects in South Africa

		Project 1	**Project 2**	**Project 3**	**Project 4**	**Project 5**
Fuel/Project		Natural gas	Wind	Coal	CFLs	Off-grid solar
Capacity	(MW)	368	5	1,974	1,080 *	17.5
Annual generation	(TWh)	2.07	0.00876	10.46	4.00 *	0.02555
Carbon intensity	kg C/kWh	0.100	0.000	0.216	0.000	0.000

* Avoided capacity and generation. Sources: Roggen (2000),Karottki and Banks (2000); Howells (1999), Eskom (2000), Qase (2000).

The two renewable electricity generation projects (2 and 5) and the electricity demand reduction project (4) all perform at or below the best plant level and better than all of the other baseline levels for the sector-wide, all-fossil, and fuel-specific baselines (see Figures 8-10). Fossil fuel projects struggle to beat the baseline if anything other than fossil fuels is included. Project 3, the efficient coal plant, only performs better than the weighted average for both the sector-wide and all-fossil baselines, but is significantly better than all baseline levels when compared to the coal-specific baseline level. Project 1, the new natural gas plant, looks best compared to fossil fuels only, since this is only coal in South Africa. The fuel-specific comparison for gas shows equal performance, since units of new gas were included in the baseline. The implication of this is that new gas projects would have to do better than ones included in the "near future" baseline.

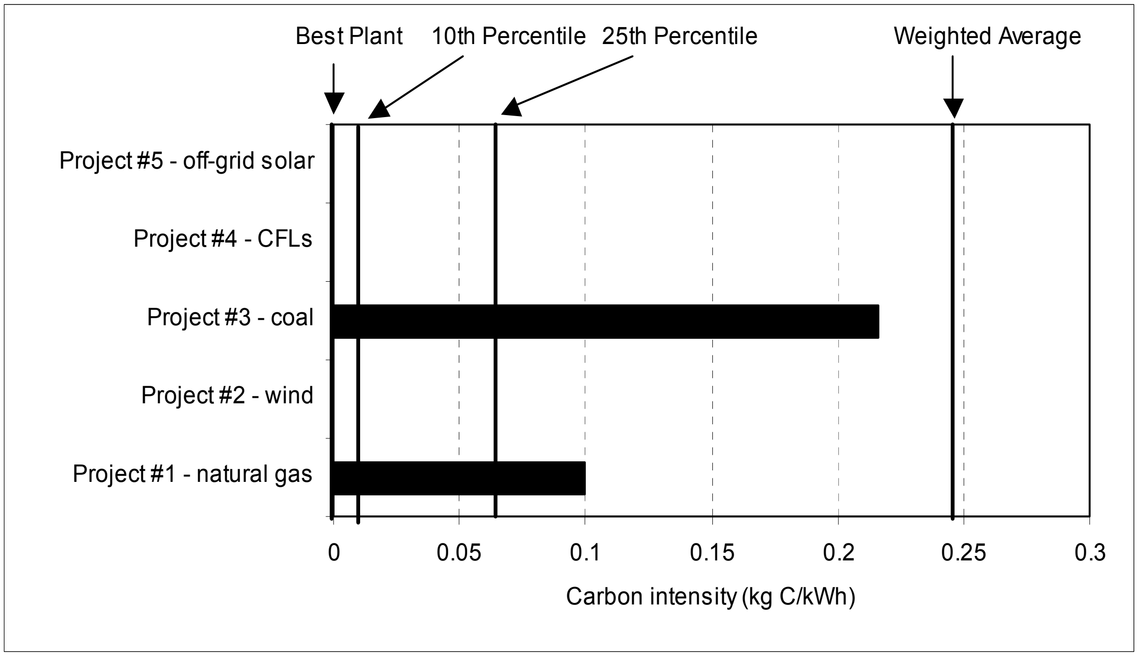

Figure 8. Carbon intensity of five hypothetical electric power projects in South Africa compared to the sector-wide baseline

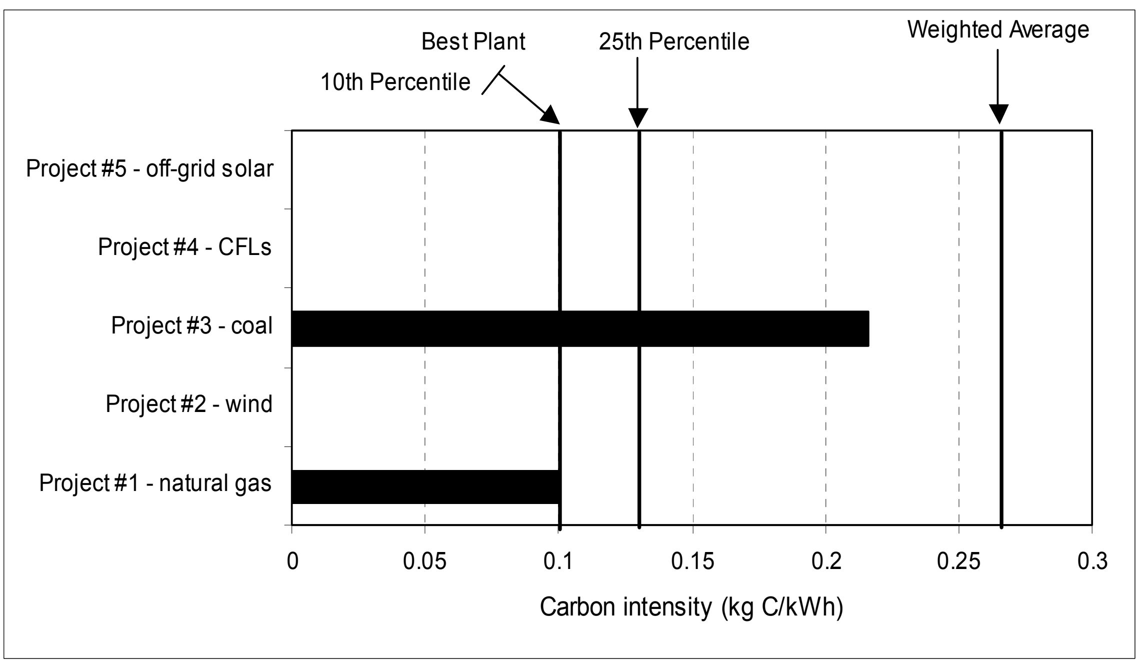

Figure 9. Carbon intensity of five hypothetical electric power projects in South Africa compared to the all-fossil baseline

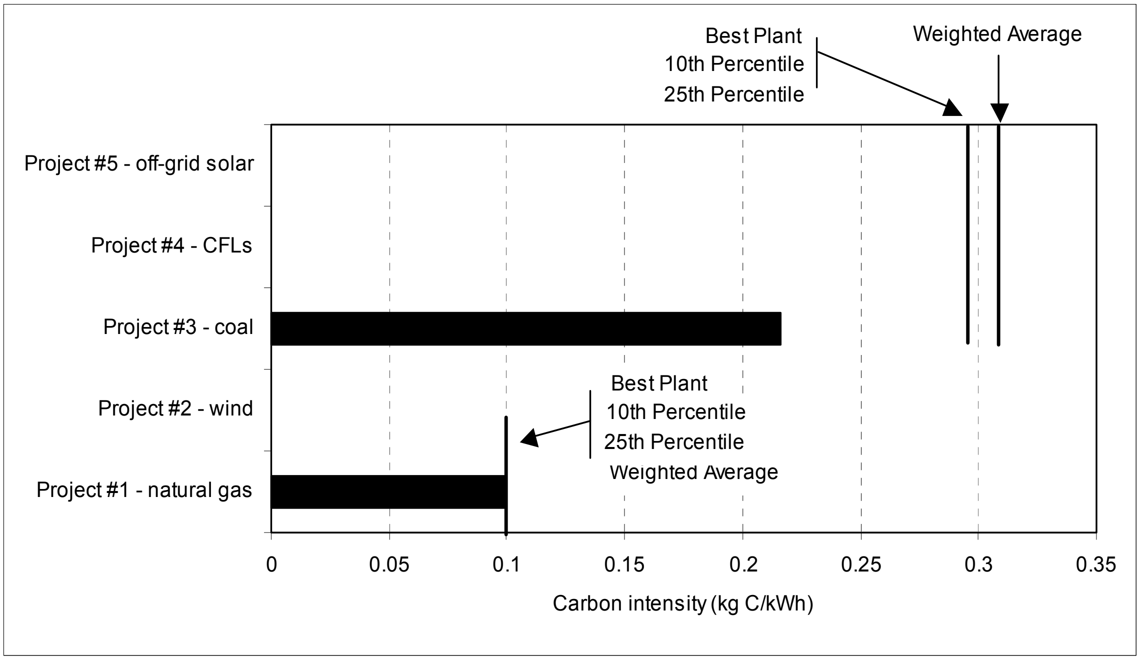

Figure 10. Carbon intensity of two hypothetical electric power projects in South Africa compared to the fuel-specific baseline

5. Findings

5.1 Methodology

5.1.1 Choosing Baseline Plants

A multi-project baseline can include either recently-constructed plants or plants that will be constructed in the near future. Of the four case studies presented in this paper, three (Brazil, China, and India) used data for recently-constructed plants, while one (South Africa) found that such an approach was inappropriate because of the small number of recent plants and significant changes in fuel mix of new, marginal plants.

For the Brazilian case study, baselines were set from fourteen relatively new cement plants. These plants were chosen because they were both the most recently built and the most modern. A forward-looking baseline would be difficult to construct for Brazil's cement sector because data on plants under construction and/or planned are not currently available. A baseline that included all plants, including older plants, would certainly differ from the one presented here, but the difference would not be substantial: the SEC for clinker production averaged 3.30 MJ/kg clinker for the baseline while the SEC for clinker production would average 3.60 MJ/kg clinker for a baseline constructed considering all the dry process plants in operation in Brazil.

For China, the baseline was established using data for six recently-built cement kilns. Due to the wide variation in technology levels seen in Chinese cement kilns, it is difficult to generalize about which kilns should be included in the construction of a baseline. Domestically-available technologies are adopted by cement plants that do not have the financial means to invest in international advanced technologies. Even so, these plants can operate as well or better than other plants due to variations in management and engineering ability among plant operators. Typically, plants that receive either foreign assistance or official key project status have the funding to adopt international advanced technologies. Which kilns should be used for establishing a multi-project baseline in China is an important topic for further research.

An issue that arose in the Chinese evaluation was that some cement plants run several kilns, each with different efficiencies. For example, one plant selected for the baseline calculation runs four kilns: one vertical kiln, two wet process kilns and one NSP kiln. The performance and energy efficiency of these kilns are quite different. The general data from the plant usually presents the average performance, which hides the significant differences in efficiency. Thus, it is important that specific kiln-based data be collected for the baseline calculations.

Recently-built electric generation plants were chosen for construction of the Indian (eastern regional) baseline. Over the last five years thirteen power plants, accounting for approximately 33% of total generating capacity, have been constructed. These recent plants reflect a wide variety in fuel types, including coal, high speed diesel oil, wind, solar, and hydro. Both the government sector and the public sector have installed new generation capacity. The installed capacity varies from 0.5 MW to 1000 MW. The near future plants are also of the similar variety both in terms of fuels and capacity and ownership pattern. Therefore, the performance of the recently-built and operating plants has been selected to construct the baseline.

In South Africa, it was not possible to construct a baseline of recently-built plants since only one power plant has been constructed in the last seven years. To use historical data, one would have to go back some 20 years or so to get a reasonable representative baseline. That would defeat the purpose of recent plant baselines, which is to include marginal, relatively efficient technologies. For this analysis, a baseline looking at six “near future” plants and units was used. Since these are future plants, the baseline itself is a projection, determined by the underlying assumptions.

The South African analysis included a comparison of the near future baseline with a recent plant baseline that used only the one recently-built plant. This comparison found that projects generally do better with the less stringent recent plant baseline since it is “easier to beat” than the harder near-future baseline, especially for the sector-wide comparison.

Thus, the four case studies show that it is more difficult to find information on near-future plants for the cement industry than for the electric power sector, where plans for capacity additions are more commonly available. The South African case study found that using recently-built plants for baseline construction could result in less stringent baselines than those based on near-future plants, assuming that the near-future plants are less carbon intensive than those recently built. However, if the planned near-future plants are more carbon intensive, as in the case of Brazil’s electricity sector for example, then a baseline using recently-built plants would be more stringent. Ultimately, the decision regarding which type of baseline to use will be determined by the host country government following analysis of the country-specific conditions.

5.1.2 Choosing Baseline Breadth

Once the baseline plants have been chosen and the baseline has been constructed, a proposed project can be compared to the baseline’s sector-wide, all-fossil, or fuel-specific carbon intensity values. In general, the case studies show that larger CERs will be realized if an all-fossil or fuel-specific baseline is used (assuming the fuel-specific baseline is based on fossil-fuel plants) because the baselines only include other fossil-fuel plants and a new fossil-fuel plant can have significant reduction in carbon intensity when compared to other fossil-fuel plants. For example, the hypothetical coal-fired plant in India (Project 3) that has a carbon intensity of 0.220 kg C/kWh, has carbon savings that are greater for the all-fossil baseline when compared to the sector-wide baseline (see Table 10). Similar results were seen in the Brazil and South Africa case studies. There was no difference between the sector-wide and all-fossil or fuel-specific baselines for China because only coal-fired cement kilns have been constructed to date.

Table 10. Comparison of Carbon Savings from a Hypothetical Coal-Fired Plant with a Carbon Intensity of 0.220 kg C/kWh in India Using All-Fossil and Sector-wide Baselines (kg C/kWh).

	Weighted Average	25th Percentile	10th Percentile	Best Plant
Baseline: All Fossil	0.345	0.241	0.217	0.217
Carbon Savings	0.126	0.021	-0.003	-0.003
Baseline: Sector-wide	0.341	0.228	0.192	0.0
Carbon Savings	0.122	0.008	-0.027	-0.220

In the South African context, even the sector-wide baseline provides a strong incentive to invest in low-carbon technologies. The actual electricity displaced by these projects will include the coal, gas and hydro-power that would likely come on line from 2000 to 2005. The projects will not only displace coal power. Hence any fossil-fuel projects that want to attract investment have to compete with gas and hydro, as do renewables. More efficient coal plants could still be developed if a weighted average benchmark is used, but the emissions reductions would be relatively small. While the purpose of the analysis is to compare baselines, rather than potential projects, we cannot avoid the issue of fossil-fuel projects. New coal would only be eligible under less stringent baselines.

5.1.3 Choosing Baseline Stringency

Once the baseline has been calculated and the breadth is chosen, then the proposed project can be evaluated based on increasingly strict baseline levels ranging from the average to the weighted average, 25th percentile, 10th percentile and best plant. The average and weighted average baselines allow the largest number of CERs and reflect the projected mix of the sector. The best plant and 10th percentile benchmarks are more restrictive, in that even renewable energy projects show only a marginal improvement in carbon intensity and many plants do not qualify for any credit at all. The 25th percentile benchmark is an intermediate choice that would still help to provide incentives to introduce advanced technologies and low- or no-carbon projects. As mentioned above, however, it can be argued that since the project has already passed some sort of additionality criteria, it is difficult to expect it to be significantly better than the weighted average plant in the multi-project baseline.

5.2 Other Issues

5.2.1 Data

One question that comes up often regarding multi-project baselines is the degree of difficulty of getting the data for different plants. In the case of Brazil, the most recent data on energy consumption for cement production are for 1995 and even so these data are not complete: no electricity consumption data on a plant-by-plant basis are available. Even so, the data available are good enough for setting the most appropriate multi-project baselines and reference values for multi-project emissions factors for the cement industry in Brazil as an alternative to project-specific baselines. Also, although the use of kiln-specific data vs. plant-specific data might be preferable in some cases, in Brazil there are no significant differences in energy efficiency between kilns at the same plant.

There is no database for the cement industry in China related to energy consumption. There are two indicators currently used to measure the energy consumption or efficiency in cement plants in China. They are specific fuel consumption for clinker production and integrated electricity consumption for cement production. If the methodology developed by LNBL is used in China, data would have to be collected for annual clinker and cement production for a plant or kiln, annual energy use of specific fuels for clinker production, and annual electricity use for the entire cement production process. It is very difficult to get data related to electricity consumption divided to different stages. Also, there is an absence of electricity consumption for kilns in the methodology.

5.2.2 Fuel Switching

Fuel switching to lower carbon fuels for either electricity generation or use in industrial processes is an option in countries or regions that have access to these fuels. However, fuel switching may not be an option in cases where natural gas or hydro is not available, where the use of these fuels is already widespread, or where other specific conditions, such as the move away from hydro in some SADC countries to mitigate the risks of drought, drive decisions.

For the Brazil case study, it was found that the widespread potential availability of low-or-zero net carbon emissions alternative fuels in most regions of the country (charcoal and sugarcane bagasse mainly) make fuel switching, rather than energy-efficiency improvements, the most effective carbon-savings option for energy-related cement projects. While increasing the energy efficiency of cement manufacture plants in Brazil can reduce, in theory, on average, carbon emissions from cement production by less than 20% at most (assuming an average SEC for clinker production of 3.6 MJ/kg clinker in the country and a "best-of-all" plant with a SEC for clinker production of 2.88 MJ/kg of clinker), fuel switching can reduce carbon emissions by up to 100% (in the case of new cement plants fueled with 100%-renewable biomass, such as increasingly-renewable charcoal and already zero-net-carbon emissions sugarcane bagasse).

Although it is clear that using low-carbon fuel for kilns and power generation can increase CO_2 reductions in China, the issue is how to develop low-carbon resources and markets. For example, after the west–to-east natural gas project is completed, 12 billion cubic meters of natural gas will be supplied to Shanghai, but the price of natural gas is projected to be higher than in most developed countries and higher than industries are willing to pay for natural gas. Overcoming such barriers to promote natural gas utilization is currently a challenge in China.

5.2.3 Process Emissions and Blended Cement

The cement industry is one of the few sectors that emits CO_2 not only from energy consumption but also from the production process. The emissions from the production process are almost equal to those from energy consumption. Improving energy efficiency can only solve part of problem. Reductions in cement utilization or in the clinker consumption for cement production are effective measures for CO_2 reduction. For example, some kinds of slag from the metallurgical industry have special characteristics that can blend with clinker to produce cement and improve the quality of cement. According to a rough estimate for China, if the cement output target is 600 million tons per year in the next two decades, 1% more slag will be used for cement production than is currently used and as a result 0.8 MtC of CO_2 will be reduced from clinker production process.

Potential project types in the cement sector can be divided into the broad categories of energy related and non-energy related. Energy-related cement projects include increasing the energy efficiency of cement manufacture, changes in the production process, and changing the input fuels to less carbon-intensive energy carriers (including less-carbon-intensive carriers for electricity production). Non-energy related cement projects include process CO_2 emissions, which can also be significantly reduced with the blending of clinker with increasing proportions of other products. This possibility, which was not examined here either but that could also be accounted for using this same methodology and the multi-project baseline model, should be also pursued in future research efforts.

6. Conclusions and Recommendations for Further Research

From the four case studies, it is clear that the most difficult aspect of setting multi-project baselines is determining the appropriate criteria in terms of baseline plants, baseline breadth, and baseline stringency in order to balance the desire to encourage no- or low-carbon projects while maintaining environmental integrity.

For Brazil, 14 recently-constructed cement plants were used to calculate the baseline. The results of the case study led the authors to conclude that, in principle, the “best plant” approach seems to be the best model for future cement plants in Brazil. That approach would not be too restrictive and, as such, would help reduce carbon emissions from energy use in the cement industry to a minimum, and, at the same time, help Brazil to get access to the most modern technology in the sector, with possible spin-offs to other industrial sectors as well. However, in some situations the “best-plant multi-project-baseline approach” may not generate enough credits to encourage potential investors-to-be on cement projects in Brazil. In summary, the results support the argument that, for the cement industry in Brazil at least, multi-project baselines based on “10th percentile” or “best plant” seem to be the most appropriate criteria for setting future baselines, by no means being too restrictive. This conclusion can be drawn in Brazil because of the opportunity to switch from fossil-fuel-based cement production to low-carbon bagasse and charcoal-based plants.

The multi-project baseline for cement plants in China was calculated using data from six recently-constructed kilns. In order to surpass expected energy efficiency levels of new cement plants in China, future projects must adopt imported advanced technologies that can beat all benchmarks according to the baselines established in this research. The project adopting advanced domestic technology only receives credit against the average and weighed average baselines. Data from kilns with advanced domestic technology level should be used for the baseline calculation in order to ensure that the project benefits the host country in terms of technology, capital and information transfer. Overall, based on the small sample size used in this evaluation, the Chinese case study led to the conclusion that in general a 10th percentile baseline eliminates the advanced domestic coal-based kilns, while providing increasing credits to domestic energy-efficient coal, imported coal, imported 50% coal/50% natural gas, and imported natural gas cement kilns, in that order. At the same time, such a baseline can identify the present advanced technology of the host country and assist in realizing technology transfer.

Recently-constructed electric power plants in the Eastern region were used to calculate the multi-project baseline for India. Using this baseline to assess a number of hypothetical plants, the case study authors concluded that in India the sector-wide baseline appears to make the most sense, because the projects will displace not only coal power by any inefficient and carbon-intensive plant. Hence any fossil-fuel projects that want to attract investments have to compete with hydro and renewables. This approach assumes that one is aiming to ensure environmental integrity.

The South Africa case study authors constructed a multi-project baseline using six plants planned for construction in the near future. The authors concluded that one option would be to use a sector-wide, 25th percentile baseline for all projects in the electricity generation sector. Another option is to choose different baselines for projects with different attributes. The advantage of a single baseline is that it is simple, and treats all technologies equally. For the electricity sector, it can include both supply and demand side options. The attraction of different baselines for different projects is that they can more accurately reflect what the project displaces and reduce free rider credits. A project-specific approach promises more accuracy in "getting the reductions right", but has higher costs.

Overall, these case studies show that it is important to fully evaluate the variety of potential baselines in order to make informed decisions regarding which plants to include in the baseline, what type of baseline to use (sector-wide, all-fossil, fuel-specific), and what level of stringency to use. The case studies presented in this paper represent an initial effort to develop and test the concept of multi-project baselines. Further research is required to fully understand the ramifications of the various choices in constructing and using these baselines. As such, we provide the following list of recommendations for additional research:

- Establishing criteria to determine which plants (or more specifically which kilns in the case of cement and which units in the case of power stations with units that differ significantly from one another) are used for establishing multi-project baselines.
- Comparing the use of recently-built to near-future baselines for specific proposed projects in a country.
- Evaluating non-energy-related cement projects that address reducing process CO_2 emissions.
- Improving data quality, e.g. actual coal consumption per power unit in the power stations rather than average consumption reported.
- Considering different types of power stations being displaced, e.g. base-load and peak-load.
- Using the plant-specific calorific value and carbon content of the fuels.
- Introducing some dynamics over time to the static analysis presented here.
- Calculating baselines for privately-owned and publicly-owned plants separately since the latter may be financially subsidized in some manner by the government.
- Analyzing the impact of matching projects with the load profile that they would displace.
- Analyzing the impact of using differentiated baselines where, for example, small-scale renewable and energy efficiency projects are automatically accepted and their savings are calculated against a sector-wide baseline in contrast to new fossil fuel projects which would be expected to meet a more stringent baseline (e.g. 10th percentile).
- Extending the analyses to larger geographical area (e.g. extend the South African analysis to the Southern African Development Community).
- Making more detailed comparison of multi-project against project-specific baseline, applied to specific projects, which may require additional project-specific studies.
- Determining the cost and amount of time required for constructing multi-project baselines
- Reducing the amount of subjectivity in constructing multi-project baselines.

Acknowledgments

This work was supported by the U.S. Environmental Protection Agency Office of Air and Radiation / Office of Atmospheric Programs through the U.S. Department of Energy under Contract No. DE-AC03-76SF00098. The authors would like to thank Ed Vine (LBNL) for his constructive comments on the paper, Amol Phadke (LBNL) for his review of the India case study, and Jane Ellis (OECD) for her thoughtful comments on the Brazilian case study.

References

Asamoah, Joe, 2000. Darling demonstrates the power of wind, African Energy Journal, vol 2 no 4., pp. 32-35

Ellis, J. and Bosi, M., 1999. Options for Project Emissions Baselines. OECD and IEA Information Paper. Paris: Organization for Economic Co-operation and Development and International Energy Agency.

Ellis, J., 2000. An Initial View on Methodologies for Emission Baselines: Cement Case Study. OECD and IEA Information Paper. Paris: Organization for Economic Co-operation and Development.

Eskom, 1996. Statistical Yearbook, Electricity Supply Commission. Sandton, South Africa: Eskom.

Eskom, 1998a. Annual Report 1998. Sandton, South Africa: Eskom.

Eskom, 1998b. IEP6: Integrated Electricity Plan for the Period 1997 – 2016. Sandton, South Africa: Eskom.

Eskom 1999. Environmental Report 1999. Sandton, South Africa: Eskom.

Eskom, 2000. Efficient Lighting Initiative. Sandton, South Africa: Eskom.

Fridley, D., Sinton, J., Lehman, B., Lewis, J., Zhou, F., Li, J., Lin, J., 2001. China Energy Databook. Version 5.0. Berkeley, CA: Lawrence Berkeley National Laboratory.

Hendriks,C.A., Worrell, E., Price, L., Martin, N., Ozawa Meida, L. 1999. Greenhouse Gases from Cement Production. IEA Greenhouse Gas R&D Programme. Report #PH3/7. Utrecht, The Netherlands: Ecofys.

Howells, Mark, 1999. Baseline and Greenhouse Gas Mitigation Options for Bulk Energy Supply, South African Country Study on Climate Change, Draft, Energy Research Institute, University of Cape Town.

International Energy Agency, 1998. World Energy Outlook – 1998 Update. Paris: IEA/OECD.

Karottki, Rene, and Doug Banks, 2000. Power and profit? Electrifying rural South Africa, Renewable Energy World Jan 2000, pp. 51-59.

Lazarus, M., Kartha, S., Ruth, M., Bernow, S., and Dunmire, C., 1999. Evaluation of Benchmarking as an Approach for Establishing Clean Development Mechanism Baselines, Boston: Tellus Institute.

Meyers, Steve, 2000. Determining Baselines and Additionality for the Clean Development Mechanism: Are Simplified Methods Viable? Forthcoming, Lawrence Berkeley National Laboratory.

MME (Ministério de Minas e Energia), 2000. Balanço Energético Nacional 1999, Brasília, Brazil:MME.

NER (National Electricity Regulator), 1999. Electricity Supply Statistics for South Africa 1999. Johannesburg: NER.

Parkinson, S., Begg, K., Bailey, P., and Jackson, T., 2001. "Accounting for Flexibility Against Uncertain Baselines: Lessons from Case Studies in the Easter European Energy Sector," Climate Policy 1(2001): 55-73.

Price, L., Michaelis, L., Worrell, E., and Khrushch, M., 1998. "Sectoral Trends and Driving Forces of Global Energy Use and Greenhouse Gas Emissions," Mitigation and Adaptation Strategies for Global Change 3: 263-319.

Price, L., Worrell, E., and Khrushch, M., 1999. Sector Trends and Driving Forces of Global Energy Use and Greenhouse Gas Emissions: Focus on Industry and Buildings. LBNL-43746. Berkeley, CA: Lawrence Berkeley National Laboratory.

Qase, Nomawethu, 2000. Too little too late: Understanding rural community reactions to Solar Home Systems in South Africa, conference paper presented East African Power Industry Convention, Kampala, 16-19 October 2000.

Roggen, Wouter, 2000. Personal communication, Athlone Power Station Manager.

Roy, J. and Das, S., 2001. Potential Multi-project Baselines for Power Sector in the Eastern Region of India.

Ruth, M., Worrell, E., and Price, L., 2000. Evaluating Clean Development Mechanism Projects in the Cement Industry Using a Process-Step Benchmarking Approach. LBNL-45346. Berkeley, CA: Lawrence Berkeley National Laboratory.

SANEA, 1998. South Africa Energy Profile. Sandton, South Africa: South African National Energy Association.

Schaeffer, R. and Costa, M. M., 2001. The Impact of Multi-project Baselines on CDM Projects in the Cement Industry in Brazil.

SNIC, 1996. Sindicato Nacional da Indústria do Cimento. SNIC, Rio de Janeiro, Brazil.

SNIC, 1999. Sindicato Nacional da Indústria do Cimento. SNIC, Rio de Janeiro, Brazil.

U.S. Energy Information Administration, 1999. India: Environmental Issues. November. http://www.eia.doe.gov/emeu/cabs/indiaenv.html

Wang, Y., 2001. Multi-Project Baselines for CDM Projects: Case Study for the Cement Industry in China.

Winkler, H., Spalding-Fecher, R., Afrane-Okese, Y., and Davidson, O., 2000. Potential Multi-project Baselines in the Power Sector in South Africa. Cape Town, SA: University of Cape Town, Energy & Development Research Centre.

World Bank Prototype Carbon Fund, 2000. Learning from the Implementation of the Prototype Carbon Fund. Washington, DC: World Bank.

Ybema, J R, Cloin, J, Nieuwenhout, F D J, Hunt, A C & Kaufman, S L 2000. Towards a streamlined CDM process for Solar Home Systems: Case studies in selected countries. Petten, Netherlands, ECN.

LBNL-48242A

The Impact of Multi-Project Baselines on CDM Projects in the Cement Industry in Brazil

Roberto Schaeffer and Márcio Macedo Costa
Energy Planning Program, COPPE, Federal University of Rio de Janeiro
C.P. 68565, Centro de Tecnologia, Sala C-216, Cidade Universitária, Ilha do Fundão
21945-970 Rio de Janeiro, RJ, Brazil

Jayant Sathaye and Lynn Price, Editors
International Energy Studies Group, Energy Analysis Department
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory
1 Cyclotron Road, MS 90-4000
Berkeley, CA 94720 USA

2001

The Impact Of Multi-Project Baselines On CDM Projects In The Cement Industry In Brazil

Table of Contents

The Impact of Multi-Project Baselines on CDM Projects in the Cement Industry in Brazil

Roberto Schaeffer* and Márcio Macedo Costa
Energy Planning Program, COPPE, Federal University of Rio de Janeiro

Abstract

This study aims to test a methodology for developing standardized approaches for setting multi-project baselines, to test reference values for multi-project emissions factors (MPEFs), and to apply these to the cement industry in Brazil as an alternative to project-specific baselines for purposes of CDM projects in the industrial sector. Its purpose is to contribute to improve the consistency, transparency and credibility of the process to establish CDM project additionality, and to reduce establishment and validation costs of CDM projects in general and of CDM cement projects in Brazil in particular. It does so by constructing four kinds of multi-project baselines: weighted average, 25th percentile, 10th percentile and best plant.

Baselines are set from fourteen relatively new existing cement plants in the country, five of which are oil-fueled, four are coal-fueled and five are multi-fueled. These plants were chosen because they are the most recently built and the most modern in operation in the country, and also because data on plants under construction and/or planned are not currently available.

Although electricity consumption data for grinding are not available on a plant-by-plant basis in Brazil, because more than 95% of all electricity consumed in the country is hydro-based, electricity–efficiency gains in grinding would only have minor impacts on carbon credits for future CDM-candidate cement plants. Also, in spite of the fact that cement production also includes process CO_2 emissions (which can be reduced through blending), only emissions associated with energy use were examined here.

Having all these constraints in mind, results show that the widespread potential availability of alternative fuels in most regions of the country (renewable charcoal and sugarcane bagasse mainly) make fuel switching, rather than energy-efficiency improvements, the most effective carbon-savings option for energy-related CDM cement projects in Brazil. And with respect to setting the most appropriate multi-project baselines, and reference values for MPEFs, the 10th percentile and the best plant approaches seem to be the most adequate ones for future CDM baselines, by no means being too restrictive in the case of the cement industry in Brazil.

Keywords: Multiproject baselines, CDM, cement industry

* To whom all correspondence should be addressed. E-mail: roberto@ppe.ufrj.br, Phone: +55-21-562-8760, Fax: +55-21-562-8777.

1. Introduction

The entering into force of the Kyoto Protocol implies that Annex B countries (38 nations and the European Union) will have obligations to comply with quantitative limitations of greenhouse gas (GHG) emissions in the near term. Because of that, the utilization of the flexible mechanisms agreed upon in Kyoto to help achieve their emissions reduction targets (Emissions Trading-ET, Joint Implementation-JI and the Clean Development Mechanism-CDM) will certainly play an important role in the agenda of some of Annex B countries in the near future.

Of the three flexible mechanisms that grew out of the United Nations Framework Convention on Climate Change (FCCC) and its Kyoto Protocol, CDM seems to be the most innovative one. CDM, defined in Article 12 of the Kyoto Protocol to the FCCC, combines technology transfer, sustainable development and climate change mitigation through specific projects in developing countries, with emission reductions resulting from each project activity having to be certified by operational entities to be designated by the Conference of the Parties on the basis of, among other things, real and measurable reductions in emissions that are additional to any that would occur in the absence of the certified project activity. If properly deployed, CDM could result in substantial cost savings in meeting national emission reduction targets for Annex B countries, while potentially helping to transfer technology and resources to developing countries and countries with economies in transition (Metz et al., 2000).

One critical difficulty associated with CDM lies in determining how to count the emissions reductions that would accrue from projects. Because the Kyoto Protocol called for no new commitments for developing countries, there would be no national “cap” on emissions against which reductions might be measured and, as such, CDM was to count reductions project by project only (OECD/IEA, 2000).

One solution is to develop emission baselines for projects. But the main question with respect to CDM baselines seems to be to find a methodology able to balance the conflict between maximizing the environmental integrity of a project and minimizing the transaction cost of the CDM. One possibility of finding a cost-effective way of determining a baseline while, at the same time, ensuring environmental integrity is to develop standardized, or multiproject, baseline procedures (Joint Implementation Quarterly, 2000).

This study aims to test a methodology for developing standardized approaches for setting multi-project baselines, to test reference values for multi-project emissions factors (MPEFs), and to apply them to the cement industry in Brazil as an alternative to project-specific baselines for purposes of CDM projects in the industrial sector. Its purpose is to contribute to improve the consistency, transparency and credibility of the process to establish CDM project additionality, and to reduce establishment and validation costs of CDM projects in general and of CDM cement projects in Brazil in particular.

2. Methodology

The authors collected data; modified and adapted a model originally developed by researchers from the Lawrence Berkeley National Laboratory (LBNL), University of California, Berkeley, U.S.A., to establish an emissions factor for a multi-project baseline; and applied the modified model and conducted studies on the cement industry in Brazil.

Initially the authors collected data on individual cement plants in Brazil about energy use, carbon emissions and output. Then, after modifying and adapting the model to the specificities of the Brazilian cement sector (a function, mainly, of the widespread use of renewable biomasse energy), the authors estimated the weighted average, top 25th and 10th percentile and best plants MPEFs for fourteen recent cement plants -- increasing methodological accuracy (but decreasing certainty) of MPEFs would have been obtained if emissions for under-construction or near-future cement plants were estimated instead. Unfortunatelly, no data of this kind are currently available in Brazil. Finally, the authors compared estimated MPEFs with CDM-project energy-efficient or CDM-project fuel-substitution plants to calculate additional carbon emissions reduction.

3. Outlook for the cement sector in Brazil

Cement production has grown steadily in Brazil in the past three decades (see Figure 1). Just five years ago, in 1995, Brazil was the thirteenth largest cement producer in the world (SNIC, 1996). In 1996, the country was already the eighth largest producer, the seventh in 1997 and the sixth in 1998 (SNIC, 1999).

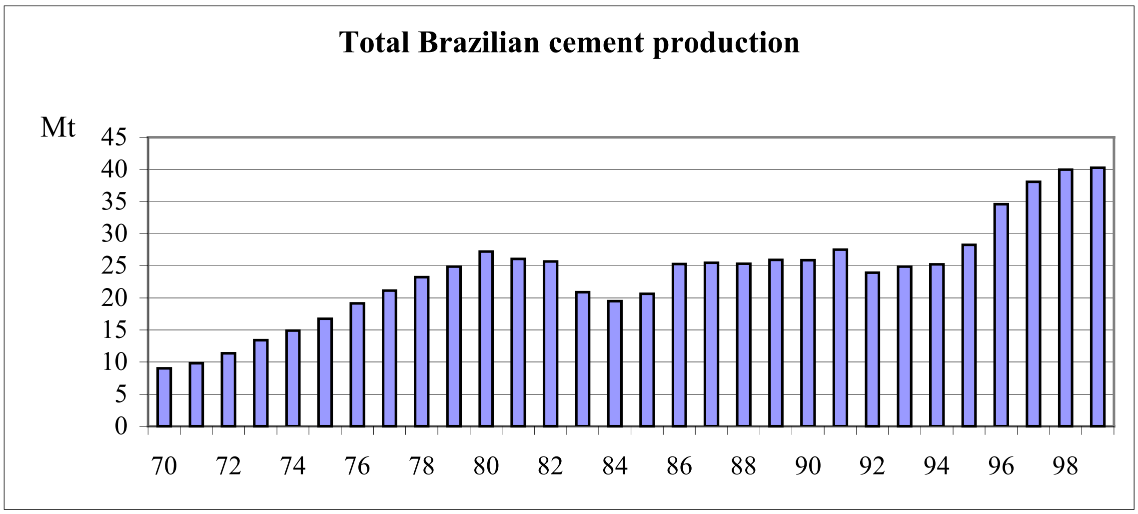

Figure 1. Portland cement production in Brazil, 1970-1999

In 1998, the country had a total production/consumption of some 40 Mt of cement (or some 250 t of cement/capita), out of a world production of 1,536 Mt of cement (SNIC, 1999). That year, 41 different companies, with 59 producing plants (with 11 grinding-only plants), were in operation in Brazil.

4. Energy use and carbon dioxide emissions from cement production

Cement manufacture is very energy intensive and results in significant energy-related and process emissions of greenhouse gases, mainly CO_2.

Basically, there are three main stages in cement production: (a) raw materials preparation; (b) clinker production; and (c) clinker grinding and blending with other products to produce cement. Of these three main steps in cement manufacture, the second one, clinker production, is the most energy intensive and is also the main source of process CO_2 emissions. Although process emissions can account, in some cases, for more than half of emissions from cement production (OECD/IEA, 2000), only energy-use-derived emissions are dealt with in this work.

Clinker can be produced by four different manufacturing processes. The name of the process refers basically to how the raw materials are mixed: (a) dry process; (b) wet process; (c) intermediate process (semi-dry or semi-wet); and (d) shaft. The first two are the main processes in use in Brazil.

The dry process is much less energy-intensive than the wet process, normally requiring 50% less energy input. The wet process is gradually being discontinued in many countries and is rarely used for new plants (OECD/IEA, 2000).

Several factors affect the energy and/or carbon intensity of cement production: (a) the process used in the manufacturing process; (b) the energy carriers consumed; (c) the manufacturing technologies deployed; (d) the type of cement produced; (e) the physical and chemical properties of the raw materials used; (f) the carbon intensity of electricity consumed in cement manufacture; and (g) the proportion of clinker in cement (OECD/IEA, 2000). All these factors have been considered in, and influenced the results of, this work.

In the case of Brazil, installed capacity for clinker production was 40.2 Mt clinker/year in 1995, with 114 kilns in operation. Of this total, 96.2% of total production was dry process, 3.3% was wet process and 0.5% was semi-dry process, with the sector being relatively efficient compared to other countries. The total energy use per unit of output, or specific energy consumption (SEC), for clinker production averaged 3.6 MJ/kg clinker, with a range of 3.09-4.42 MJ/kg clinker for the dry process plants and 6.02-7.59 MJ/kg clinker for the wet process plants (SNIC, 1996).

Due to its extremely high energy intensity and large volumes of production involved, cement manufacture in Brazil accounted for 7%, 4% and 5% of total energy use in the industrial sector in

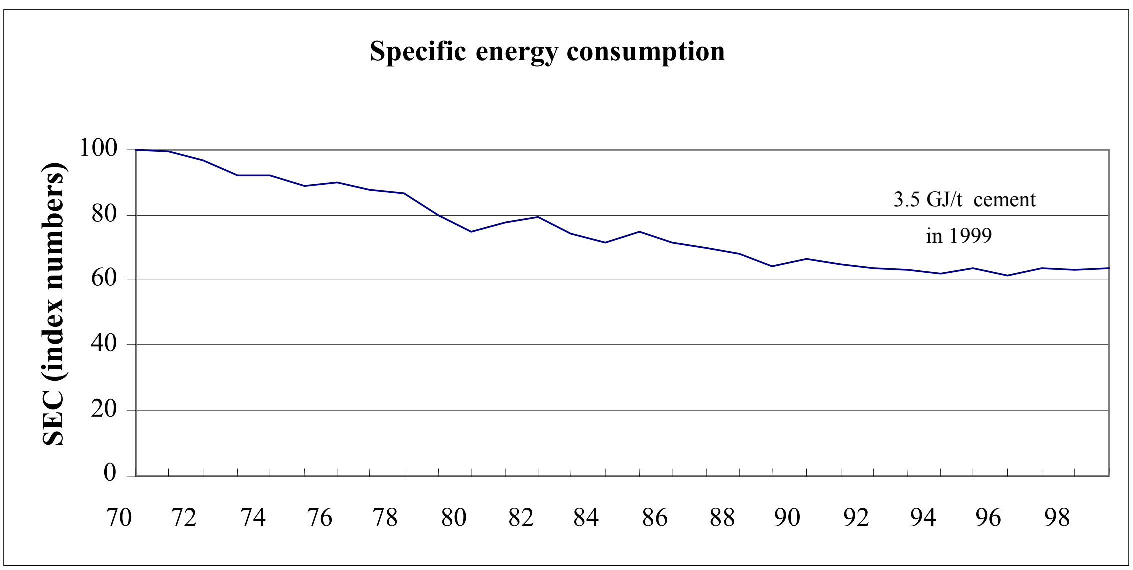

Figure 2. Specific energy consumption (SEC) for cement production in Brazil

1970, 1995 and 1999, respectively, behind only the food and beverages sector (20% of total energy use in the industrial sector in 1999), the iron and steel sector (19%), the non-ferrous metals sectors (12%), the chemicals sector (11%), and the pulp and paper sector (9%). In terms of carbon emissions from energy use, cement manufacture accounted for 7% of total industrial emissions in the country in 1994 (MME, 2000). Figures 2 and 3 depict, respectively, SEC (total energy use per tonne of cement) and specific carbon emissions (SCE)(total carbon emissions per tonne of cement) from energy use for cement production in Brazil during the past 30 years.

Interestingly enough, several factors have contributed to these decreases in specific energy and carbon intensities of cement production over time in Brazil. Among those are worth mentioning, in different proportions, are the changes in the production process by which raw materials are ground, mixed and fed into the kilns from wet to dry (with impacts in both energy use and carbon emissions), the increase in the energy efficiency of cement production in general by optimizing heat uses (also with impacts in both energy use and carbon emissions), and changes in the input fuel (with impacts mostly on the carbon intensity from energy use). This latter factor explains the increase in SCE from energy use for cement production in Brazil in the last couple years: the substitution of higher-carbon-content petroleum coke for lower-carbon-content fuel oil, coal and charcoal as an input fuel.

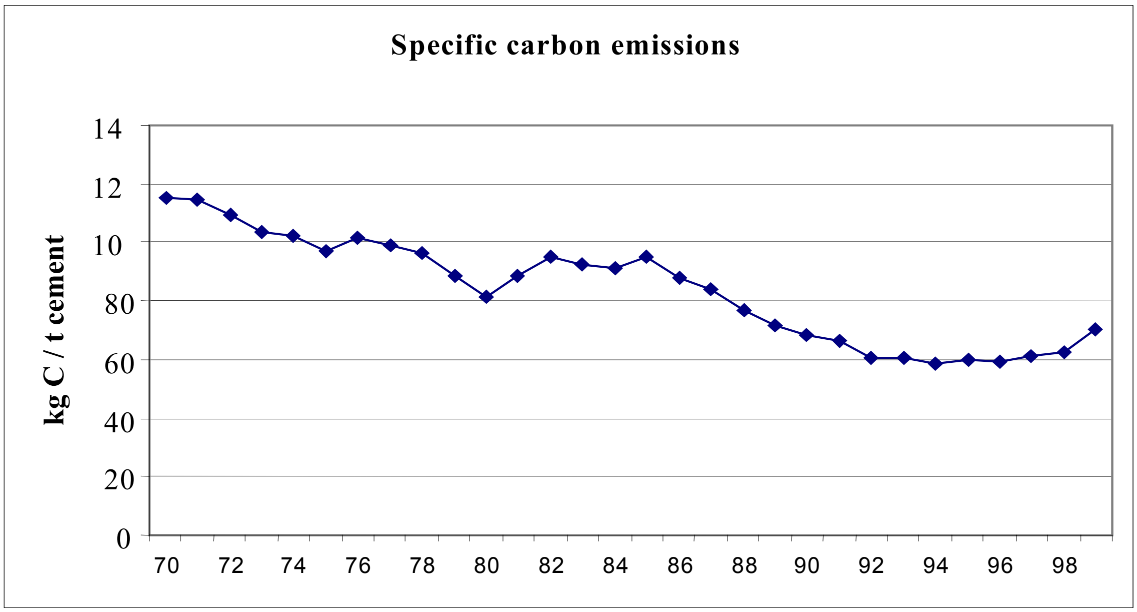

Figure 3. Specific carbon emissions (SCE) from energy use for cement production in Brazil

Figure 4 presents shares of different energy carriers used as fuel inputs in cement production in Brazil during the past 30 years. Due to the high temperatures present in a cement kiln (in the range of 1500 ^{o}C), a wide range of input fuels, including waste fuels, can be, and were, safely used.

While in the early 70s fuel oil was almost exclusively used as the fuel input for cement manufacture in Brazil, its use decreased steadily until the middle of the 80s, when it started to grow in importance again until approximately 1989. The roles of coal and charcoal were exactly the opposite of – and compensating – the role of fuel oil, growing in importance until the middle of the 80s, and decreasing after that. Oil prices in the domestic market and domestic policies after 1985 requiring renewable charcoal to be used (Figure 5 shows, for the 90s, the growing share of renewable charcoal on total charcoal use in Brazil) explain most of these trends. In 1999, with natural gas becoming increasingly available in Brazil, the excess of petroleum coke in the market found its way as an important fuel input for cement production in the country.

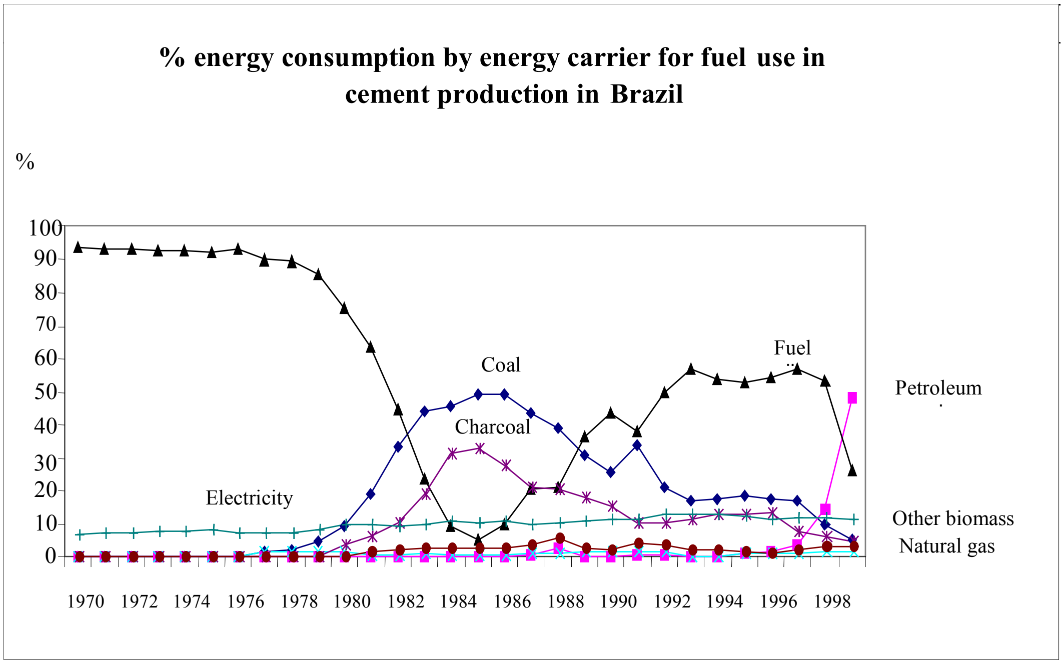

Figure 4. Share of different energy carriers as fuel inputs in cement production in Brazil

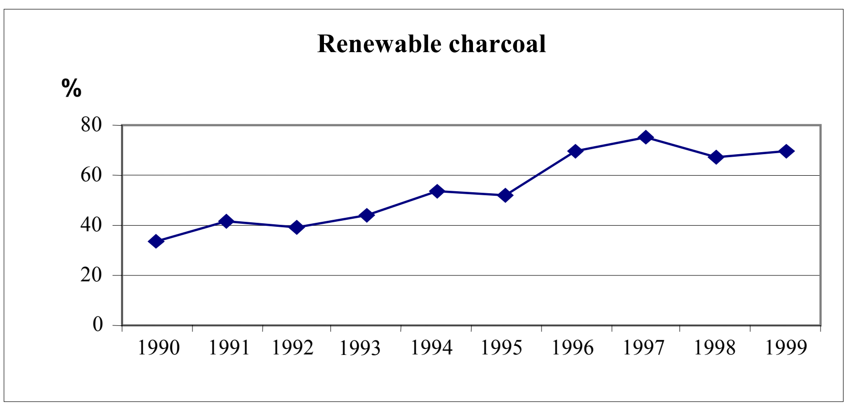

Figure 5. Share of renewable charcoal on total charcoal use in Brazil

5. Multi-project baselines construction

Emissions from the production of cement depend on various factors (see section 4). Even so, emissions from energy use from the manufacture of cement can be expressed as following:

Total emissions from energy use for cement production	=	emissions from fuel combustion + (indirect) emissions from electricity consumed

As we can see, the key underlying assumptions of emission baselines in cement production concern, mostly, the energy used in the different manufacturing processes. In our case, the multi-project baseline energy and carbon (from energy use only) intensities of cement manufacture are based on data from 1995, the last year for which information on fuel energy consumption is available on a plant-by-plant basis.

Regarding electricity consumption, data on a plant-by-plant basis is not currently available in Brazil. For the whole Brazilian cement sector, on the other hand, the electricity consumption was 116 kWh per tonne of cement in 1995 and 112 kWh per tonne of cement in 1999 (MME, 2000). However, it should be noted that total energy consumption remained the same, 3.5 GJ/t cement, from 1995 to 1999 (MME, 2000). Considering that the average clinker/cement ratio has kept at the same level (0.8) over time and that no significant process changes have occurred since 1995, using 1995 data by plant seems to be reasonable.[1] It is true that petroleum coke consumption for clinker production increased heavily in 1999 (Figure 4), resulting in higher carbon emissions per ton of clinker produced (Figure 3), as petroleum coke presents a higher carbon content than coal and fuel oil.

Net specific carbon emissions from energy use are shown in Table 1. Notice that sugarcane bagasse is a renewable energy source, resulting in zero net carbon emissions. The evolution of charcoal renewability in Brazil is presented in Figure 5.[2] In 1999, 70% of the produced charcoal was renewable, resulting in net carbon emissions of 9.7 kg C/GJ of charcoal.

Therefore, baseline intensities based on 1995 data are more restrictive, meaning that if a CDM project is approved for 1995 baselines, it will certainly be approved for 1999-constructed baselines as well.

In this study, baselines are set from fourteen relatively new existing cement plants in the country, five of which are oil-fueled, four are coal-fueled and five are multi-fueled. The main criterion used for choosing plants was to build a baseline composed only of highly energy efficient clinker production units. These fourteen plants are the most recently built and the most modern plants in operation in the country today. A baseline that included plants under construction or planned plants is not considered because such information is currently not available in Brazil.

Table 1. Net carbon emissions from selected energy carriers in Brazil

Net carbon emissions (kg C/GJ)	
Coal	25.8
Natural gas	15.3
Fuel oil	21.1
Petroleum coke	27.5
Charcoal (0% renewable)	32.2
Charcoal (70% renewable)	9.7
Sugarcane bagasse	0.0

As shown in Table 2, the energy and carbon intensities of oil-fueled plants (numbers 1-5) vary between 3.19-3.36 MJ/kg clinker and 67.33-70.99 kg C/t clinker, respectively. For coal-fueled plants (numbers 6-9) the ranges for energy and carbon intensities are 3.09-3.43 MJ/kg clinker and

[1] As a matter of fact, from the early 70s to the end of the 90s the use of additives for cement production has increased slightly in Brazil. As such, the average clinker/cement ratio decreased slightly in the period, which explains part of the decrease in the SEC for cement production in the country over time.

[2] Charcoal "renewability" refers to whether or not the wood for charcoal production has been harvested sustainably, i.e. produced from renewable forests rather than from deforestation.

79.69-88.47 kg C/t clinker, respectively. The group of plants (numbers 10-14) consuming more than one fuel presents energy intensities varying between 3.22-3.41 MJ/kg clinker and an extremely wide range of carbon intensities (31.73-79.91 kg C/t clinker). The plant with the highest share of charcoal consumption on total fuel inputs presents the lowest carbon intensity, 31.73 kg C/t clinker.

Baselines for the raw material production and the cement grinding stages require information on electricity consumption on a plant-by-plant level. However, such information is not currently available in Brazil and estimated values of 26 kWh/tonne (0.12 kgC/tonne) for raw material production and 42.6 kWh/tonne (0.2 kgC/tonne) for cement grinding were used for setting the baselines for these two process steps. These estimates are based on total electricity consumption, 116 kWh/tonne cement, in the Brazilian cement sector in 1995, applying percentual values for each step in typical portland cement plants in Brazil (dry process). However, carbon emissions derived from electricity generation are extremely low in Brazil due to the fact that about 95% of all electricity generated and consumed in the country has a hydroelectric origin. Thus, electricity savings technologies are not considered in this study and the estimates for electricity consumption are illustrative only.

Also, it should be observed that some plants in Table 2 present higher figures for clinker production than for cement production. This is explained by the fact that some plants in Brazil sell part of their clinker production to third parties (to grinding-only plants).

Finally, the multi-project-baseline for the fourteen plants chosen to integrate the benchmarks yields a weighted-average SEC of 3.30 MJ/kg clinker, as shown in Table 3.

The "best plant" benchmark with respect to carbon emissions refers to a plant using almost 100% charcoal. If we consider several options for projects using different input fuels plus bagasse, we can easily calculate the maximum percentage of any fuel in these projects required to achieve this best plant benchmark, as shown in Figure 6. For example, 63% is the maximum amount of natural gas to be used (together with 37% of bagasse) in a clinker kiln in Brazil today, in order to have that plant achieving the best-plant benchmark available in the market.

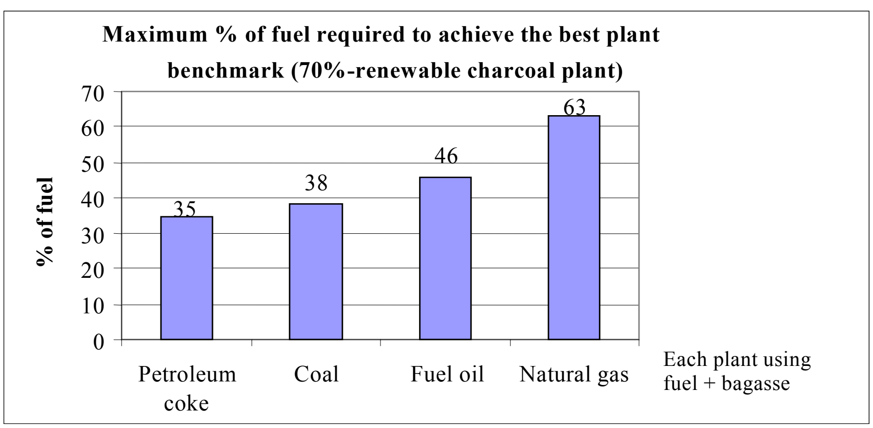

Figure 6. Maximum share of a fuel in a dual-fuel cement plant, with sugarcane bagasse as the second fuel, to achieve Brazil's best plant benchmark

Table 2. Technical characteristics of fourteen "recently-built" cement manufacturing plants in Brazil used for the construction of multi-project baselines for CDM projects

PLANT		**1**	**2**	**3**	**4**	**5**	**6**	**7**
I. Plant Performance								
Capacity	t clinker/day	3000	7200	1500	1000	900	2665	4500
raw material throughput	Mtonne/year	1.169	2.662	0.503	0.410	0.490	0.505	1.969
clinker production	Mtonne/year	0.649	1.479	0.280	0.228	0.272	0.281	1.094
cement production	Mtonne/year	0.566	2.160	0.323	0.174	0.279	0.667	1.071
Fuel consumption								
Coal	GJ						904,518	3,378,309
Charcoal	GJ							
Natural Gas	GJ							
Fuel Oil	GJ	2,072,263	4,921,445	938,363	766,881	882,756		
Other (100% renewable)	GJ							
II. Plant Intensities								
total fuel usage	GJ	2,072,263	4,921,445	938,363	766,881	882,756	904,518	3,378,309
total carbon emissions	tonne C	43,725	103,842	19,799	16,181	18,626	23,337	87,160
energy intensity	GJ/t clinker	3.19	3.33	3.36	3.36	3.25	3.22	3.09
carbon intensity	kg C/t clinker	67.33	70.22	70.79	70.99	68.48	83.11	79.69
PLANT		**8**	**9**	**10**	**11**	**12**	**13**	**14**
I. Plant Performance								
Capacity	t clinker/day	2200	2200	2000	2910	2200	10200	1920
raw material throughput	Mtonne/year	1.109	0.752	0.810	1.725	1.140	4.014	0.809
clinker production	Mtonne/year	0.616	0.418	0.450	0.958	0.633	2.230	0.450
cement production	Mtonne/year	0.692	0.557	0.590	1.150603	0.717218	2.036486	0.36176
Fuel consumption								
Coal	GJ	2,053,902	1,433,205		40,432		3,817,247	1,129,037
Charcoal	GJ			1,425,405	677,200	803,681		
Natural Gas	GJ							
Fuel Oil	GJ			21,099	2,440,744	1,264,397	3,777,810	19,197
Other (100% renewable)	GJ							356,723
II. Plant Intensities								
total fuel usage	GJ	2,053,902	1,433,205	1,446,505	3,158,376	2,068,078	7,595,057	1,504,956
total carbon emissions	tonne C	52,991	36,977	14,272	59,112	34,474	178,197	29,534
energy intensity	GJ/t clinker	3.33	3.43	3.22	3.30	3.27	3.41	3.35
carbon intensity	kg C/t clinker	85.99	88.47	31.73	61.69	54.46	79.91	65.68

Table 3. Multi-project baseline outputs based on fourteen "recently-built" cement plants in Brazil

Clinker Production Stage			*Benchmark Basis:* Average	Weighted Average	Percentile 25%	Percentile 10%	Best Plant
energy intensity	GJ/tonne	all	3.29	3.30	3.16	3.09	3.09
		coal	3.27	3.23	3.09	3.09	3.09
		charcoal	*****	*****	*****	*****	*****
		ng	*****	*****	*****	*****	*****
		fuel oil	3.30	3.30	3.20	3.19	3.19
carbon intensity	kg C/tonne	all	69.90	71.56	55.25	44.27	31.73
		coal	84.31	83.22	79.69	79.69	79.69
		charcoal	*****	*****	*****	*****	*****
		ng	*****	*****	*****	*****	*****
		fuel oil	69.56	69.53	67.46	67.33	67.33

6. Hypothetical CDM-candidates cement projects

Tables 4 and 5 present information on the six hypothetical CDM-candidate cement projects considered in this study. Project 1 refers to a plant with 0.65 Mt of clinker annual production and 0.57 Mt of cement annual production using 100% of fuel oil with the "best plant" SEC of 3.09 GJ/t clinker. Projects 2-4 refer to plants with 1.09 Mt of clinker annual production and 1.07 Mt of cement annual production, with the "best plant" SEC of 3.09 GJ/t clinker and using 100% of a different fuel each (natural gas, charcoal and bagasse). Projects 5-6 refer to plants with 1.50 Mt of clinker annual production and 1.90 Mt of cement annual production using 100% of coal and 100% of natural gas respectively, both with SECs of 3.15 GJ/t clinker.

Table 4. Basic description of hypothetical CDM-candidate cement manufacture projects

Project #	Fuel	Clinker Production (Mt)	Cement Production (Mt)	Specific Energy Consumption (GJ/t clinker)
1	Oil	0.65	0.57	3.09
2	Natural gas	1.09	1.07	3.09
3	Charcoal	1.09	1.07	3.09
4	Bagasse	1.09	1.07	3.09
5	Coal	1.50	1.90	3.15
6	Natural gas	1.50	1.90	3.15

7. Results

Table 6 and Figures 7, 8, 9 and 10, present the final results of the study. SCE reductions (in terms of kg C/t cement\) and total carbon emissions reductions (in terms of kg C/year) for each of the six different CDM-candidate cement projects are shown. Results are presented compared to multi-project emissions factors (MPEFs) from the multi-project baselines given in terms of weighted average, 25% percentile, 10% percentile and best plant. Comparisons are made both fuel specific, in the cases of Projects 1 and 5 (how a CDM-candidate cement project stands against the weighted average, 25% percentile, 10% percentile and best plant of plants fueled by the same kind of fuel), and sector wide, in the cases of all projects (how a CDM-candidate cement project stands against the weighted average, 25% percentile, 10% percentile and best plant of all plants considered for the baselines).

Table 5. Detailed data for hypothetical CDM-candidate cement manufacture projects

Data for Project Evaluation

PLANT NAME		Project #1	Project #2	Project #3	Project #4	Project #5	Project #6
Capacity	t/day						
I. Plant Performance							
Raw Material Grinding Stage							
raw material annual throughput	Mtonne	1.17	1.97	1.97	1.97	2.70	2.70
annual electricity consumption	GWh	30.39	51.19	51.19	51.19	70.20	70.20
Clinker Production Stage							
annual clinker production	Mtonne	0.65	1.09	1.09	1.09	1.50	1.50
annual fuel usage information:							
Coal	GJ				0.001	4,725,000	
Charcoal	GJ			3,378,309			
Natural Gas	GJ		3,378,309				4,725,000
Fuel Oil	GJ	2,005,410					
Other	GJ				3,378,308		
More than 1 fuel used?	(Y/N)	N	N	N	Y	N	N
Cement Grinding Stage					N		
annual cement production	Mtonne	0.57	1.07	1.07	1.07	1.90	1.90
annual electricity consumption	GWh	24.10	45.62	45.62	45.62	80.92	80.92
II. Plant Intensities							
Raw Material Grinding Stage							
energy intensity	kWh/tonne	26.00	26.00	26.00	26.00	26.00	26.00
carbon intensity	kg C/tonne	0.12	0.12	0.12	0.12	0.12	0.12
Clinker Production Stage							
total fuel usage	GJ	2,005,410	3,378,309	3,378,309	3,378,308	4,725,000	4,725,000
total carbon emissions	tonne C	42,314	51,688	32,770	0	121,905	72,293
energy intensity	GJ/tonne	3.09	3.09	3.09	3.09	3.15	3.15
carbon intensity	kg C/tonne	65.16	47.26	29.96	0.00	81.27	48.20
Cement Grinding Stage							
energy intensity	kWh/tonne	42.59	42.59	42.59	42.59	42.59	42.59
carbon intensity	kg C/tonne	0.20	0.20	0.20	0.20	0.20	0.20

Note: The annual electricity consumption values were calculated indirectly from the set values for energy intensities

In the case of CDM-candidate cement project 1 (oil), in a fuel-specific comparison the project performs well against any baseline. In a sector wide comparison, on the other hand, carbon reductions are only possible against the weighted-average baseline. The reason for these outcomes is that the SEC of CDM-candidate cement project 1 (3.09 MJ/kg clinker) is equal to the SEC of the most efficient cement manufacture plant in the country today (a coal-fueled cement plant), and as such is lower than the SEC of any other fuel-oil-fueled cement plant available. But in a sector-wide comparison, even the high energy efficiency of this plant cannot compete, in terms of carbon emissions, with other less energy-efficient cement plants fueled with natural gas and partially-renewable (70%) charcoal.

In the case of CDM-candidate cement project 2 (natural gas), in a sector-wide comparison carbon reductions are only possible against the weighted-average and the 25th-percentile baselines. In this case, the reason is that the 10th-percentile and best-plant baselines are composed of charcoal plants, which, although not being as energy efficient, in terms of carbon emissions, at least, perform better than even an energy-efficient natural gas cement plant.

Table 6. Carbon emissions reductions for hypothetical CDM-candidate cement projects against multi-project emissions factors (MPEFs)

Carbon intensity reductions [kg C/ tonne cement] (clinker production only)
Project performs this much lower *than benchmark; bigger number is better*

Compared to	*Benchmark standard*	Project #1	Project #2	Project #3	Project #4	Project #5	Project #6
Fuel specific	Weighted average	4.367	dna	dna	dna	1.952	dna
	25th percentile	2.294	dna	dna	dna	-1.585	dna
	10th percentile	2.172	dna	dna	dna	-1.585	dna
	Best plant	2.172	dna	dna	dna	-1.585	dna
Sector wide	Weighted average	6.394	24.301	41.597	71.556	-9.714	23.361
	25th percentile	-9.908	7.999	25.295	55.254	-26.016	7.059
	10th percentile	-20.889	-2.982	14.314	44.274	-36.996	-3.921
	Best plant	-33.430	-15.523	1.773	31.732	-49.538	-16.463

Carbon reductions [kilotons per year; '000s of tons] (clinker production only)

Compared to	*Benchmark standard*	Project #1	Project #2	Project #3	Project #4	Project #5	Project #6
Fuel specific	Weighted average	2.8	dna	dna	dna	2.9	dna
	25th percentile	1.5	dna	dna	dna	none	dna
	10th percentile	1.4	dna	dna	dna	none	dna
	Best plant	1.4	dna	dna	dna	none	dna
Sector wide	Weighted average	4.2	26.6	45.5	78.3	none	35.0
	25th percentile	none	8.7	27.7	60.4	none	10.6
	10th percentile	none	none	15.7	48.4	none	none
	Best plant	none	none	1.9	34.7	none	none

Note: dna stands for "does not apply"

In the cases of CDM-candidates cement projects 3 (charcoal) and 4 (bagasse), in sector wide comparisons carbon reductions are possible against any baselines. In these cases, the outcomes are obvious. No cement plants in operation in Brazil today can perform better, in terms of carbon emissions, than energy-efficient plants fueled by 70%-renewable biomass (in the case of CDM-candidate cement project 3, which is fueled by charcoal) or 100%-renewable biomass (in the case of CDM-candidate cement project 4, which is fueled by sugarcane bagasse).

In the case of CDM-candidate cement project 5 (coal), in a fuel-specific comparison the project performs well only against the weighted-average baseline. In a sector-wide comparison, the project never performs well. It yields carbon emissions that are higher than any baseline considered. Here, too, these results come at no surprise. The very existence of cement manufacture plants in Brazil running on renewable biomass precludes the possibility of less energy-efficient coal-fueled cement manufacture plants performing well against sector-wide multi-project baselines.

Finally, in the case of CDM-candidate cement project 6 (natural gas), in a sector wide comparison carbon reductions are only possible against the weighted-average and the 25th-percentile baselines. The reasons for that performance are similar to those presented for the results of CDM-candidate cement project 2.

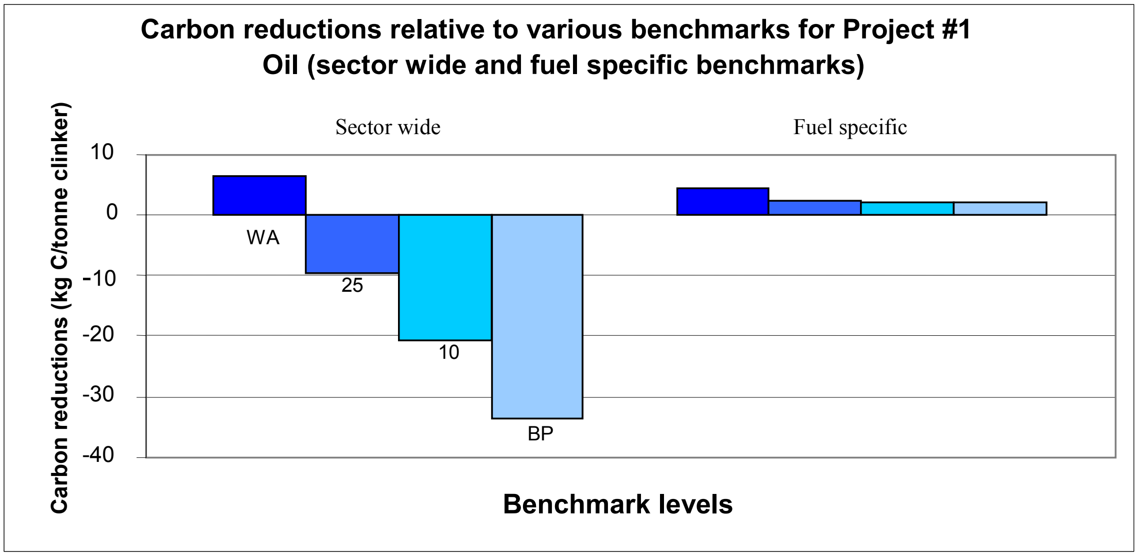

Figure 7. Carbon reductions for CDM-candidate cement manufacture Project #1 against fuel-specific and sector-wide multi-project baselines

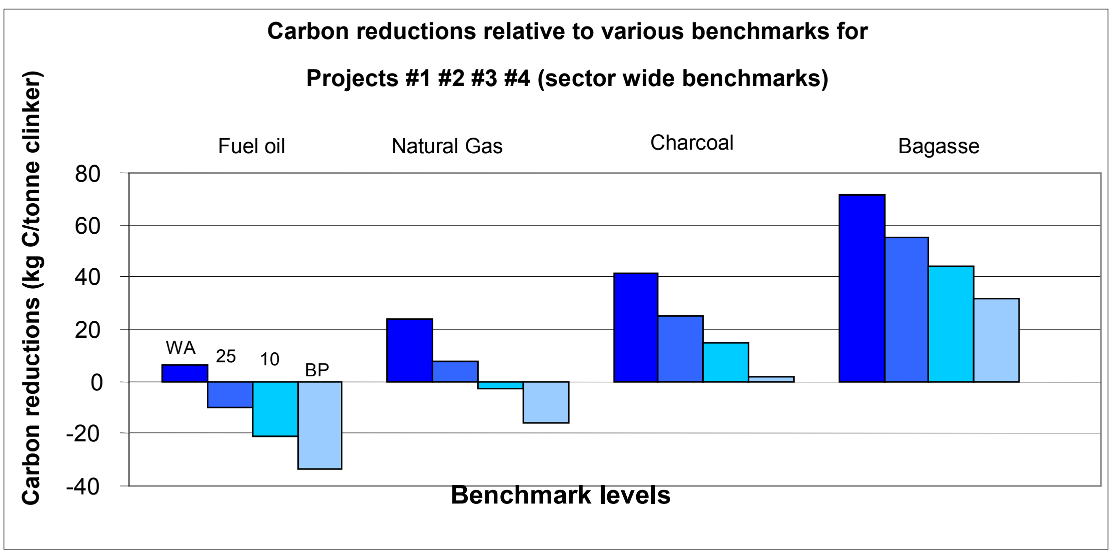

Figure 8. Carbon reductions for CDM-candidate cement manufacture Projects #1-4 against sector-wide multi-project baselines

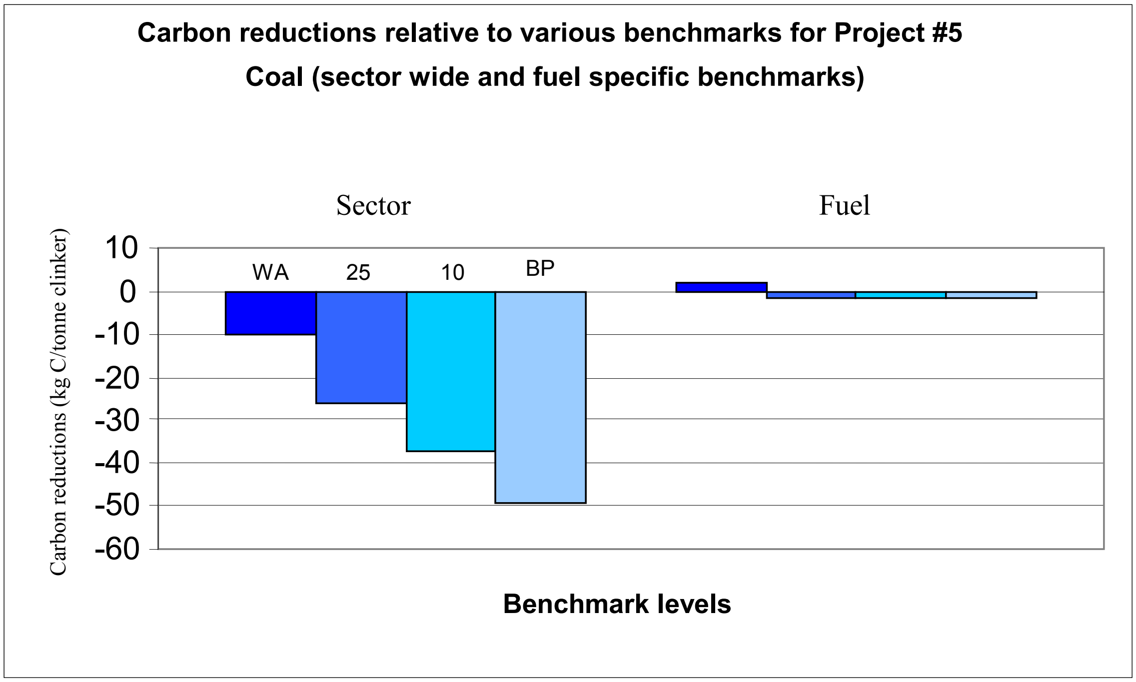

Figure 9. Carbon reductions for CDM-candidate cement manufacture Project #5 against fuel-specific and sector-wide multi-project baselines

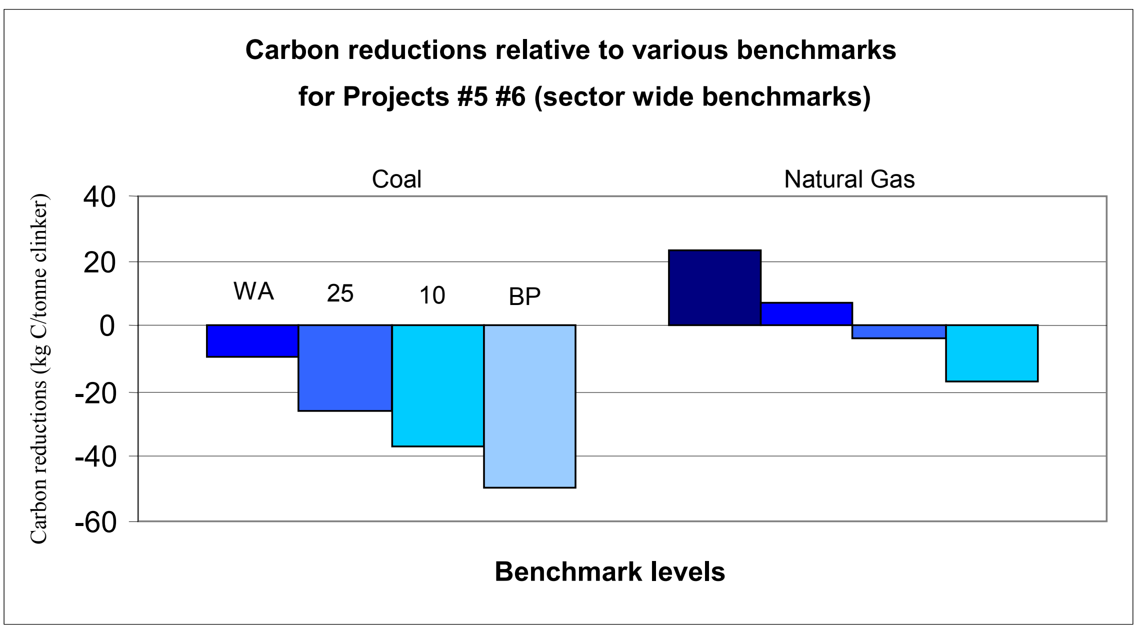

Figure 10. Carbon reductions for CDM-candidate cement manufacture Projects #5 and #6 against sector-wide multi-project baselines

8. Final discussion

Potential CDM project types in the cement sector can be divided into the broad categories of energy related and non-energy related categories. Energy-related CDM cement projects, which were the focus of this paper, include increasing the energy efficiency of cement manufacture, changes in the production process, and changing the input fuels to less carbon-intensive energy carriers (including less-carbon-intensive carriers for electricity production).

Non-energy related cement projects include process CO_2 emissions, which can also be significantly reduced with the blending of clinker with increasing proportions of other products. This possibility, which was not examined here either but that could also be accounted for using this same methodology and the multi-project baseline model, should be also pursued in future research efforts.

Baselines were set from fourteen relatively new existing cement plants in the country. These plants were chosen because they are both the most recently built and the most modern ones, and also because data on plants under construction and/or planned are not currently available in Brazil. A baseline that included all plants, including older plants, would certainly differ from the one presented here, but the difference would not be substantial: the SEC for clinker production averaged 3.30 MJ/kg clinker for our baseline while the SEC for clinker production would average 3.60 MJ/kg clinker for a baseline constructed considering all the dry process plants in operation in Brazil.

Interestingly enough, the widespread potential availability of low-or-zero net carbon emissions alternative fuels in most regions of the country (charcoal and sugarcane bagasse mainly) make fuel switching, rather than energy-efficiency improvements, the most effective carbon-savings option for energy-related CDM cement projects in Brazil. While increasing the energy efficiency of cement manufacture plants in Brazil can reduce, in theory, on average, carbon emissions from cement production by less than 20% at most (assuming an average SEC for clinker production of 3.6 MJ/kg clinker in the country and a "best-of-all" plant with a SEC for clinker production of 2.88 MJ/kg of clinker), fuel switching can reduce carbon emissions by up to 100% (in the case of new cement plants fueled with 100%-renewable biomass, such as increasingly-renewable charcoal and already zero-net-carbon emissions sugarcane bagasse).

One question that comes up often regarding multi-project baselines is how difficult is to get the data for different plants. In the case of Brazil, the most recent data on energy consumption for cement production are for 1995 and even so these data are not complete: no electricity consumption data on a plant-by-plant basis are available. Even so, the data available are good enough for setting the most appropriate multi-project baselines and reference values for MPEFs for the cement industry in Brazil as an alternative to project-specific baselines for purposes of CDM projects. Also, although the use of kiln-specific data vs. plant-specific data might be preferable in some cases, in Brazil there are no significant differences in energy efficiency between kilns at the same plant.

The discussion presented leads us to conclude that, in principle, the "best plant" approach seem to be the best model for future CDM-candidate cement plants in Brazil. That approach, as we have shown, would not be too restrictive and, as such, would help reduce carbon emissions from energy use in the cement industry to a minimum, and, at the same time, help Brazil to get access to the most modern technology in the sector, with possible spill-outs to other industrial sectors as well. We have to recognize, however, that in some very few situations the "best-plant multi-project-baseline approach" may be too restrictive, perhaps even de-stimulating potential investors-to-be on CDM-cement projects in Brazil.

In any case, results clearly show that different criteria for establishing multi-project baselines may have substantial impacts on the amounts of carbon credits to be obtained from CDM-cement projects in Brazil. When all fuels are included in the multi-project baselines, fossil-fueled projects do not look good in sector-wide analyses (never beating "best plant" or 10th-percentile multi-project baselines).

Because of the wide availability of renewable biomass as input fuels for the cement industry in Brazil, even energy-efficient natural-gas-fueled plants do not perform well at the "best plant" and 10th-percentile levels sector-wide. Energy-efficient fuel-oil- and coal-fueled cement manufacture plants can only perform well compared to fuel-specific plants.

Although electricity consumption data for grinding are not easily available on a plant-by-plant basis in Brazil (it is considered a "commercial secret" by the domestic cement industry), because more than 95% of all electricity consumed in the country is hydro-based electricity–efficiency gains in grinding would only have minor impacts on carbon credits for future CDM-candidate cement plants.

In summary, the results presented here support our argument that, for the cement industry in Brazil at least, multi-project baselines based on "10th percentile" or "best plant" seem to be the most appropriate criteria for setting up future CDM baselines, by no means being too restrictive.

Acknowledgements

This paper contributes to a larger research effort coordinated by the Lawrence Berkeley National Laboratory (LBNL). LBNL supported the presentation of the results of this paper to the Sixth Conference of the Parties (COP-6) to the United Nations Framework Convention on Climate Change, held in The Hague, The Netherlands, from 13-25 November 2000. We particularly thank Jayant Sathaye, Lynn Price and Michael Ruth, from LBNL, for all the collaboration, support and precious comments provided during all the process of producing this work. We are also grateful to the financial support that was provided, in part, by CNPq, Ministry of Science and Technology, Brazil, to develop this research. The views expressed in this article are solely of the authors.

References

JIQ, 2000. "Unrealistic Baselines". *Joint Implementation Quarterly,* Special Issue for the Lyon Preparatory Conference for CoP6. August.

Metz, Bert; Davidson, Ogunlade R.; Martens, Jan-Willem; van Rooijen, Sascha N.M. and McGrory, Laura Van Wie.. *Methodological and Technological Issues in Technology Transfer*. A Special Report of IPCC Working Group III. Cambridge University Press, Cambridge.

MME, 2000. *Balanço Energético Nacional 1999*. Ministério de Minas e Energia, Brasília, Brazil.

OECD/IEA, 2000. *Emission Baselines: Estimating the Unknown*. Organization for Ecomomic Co-operation and Development and International Energy Agency, Paris.

SNIC, 1996. *Sindicato Nacional da Indústria do Cimento*. SNIC, Rio de Janeiro, Brazil.

SNIC, 1999. *Sindicato Nacional da Indústria do Cimento*. SNIC, Rio de Janeiro, Brazil.

LBNL-48242B

Multi-Project Baselines for CDM Projects: Case Study for the Cement Industry in China

Yanjia Wang
US/China Energy and Environment Technology Center
Tsinghua University
Beijing, China

Jayant Sathaye and Lynn Price, Editors
International Energy Studies Group, Energy Analysis Department
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory
1 Cyclotron Road, MS 90-4000
Berkeley, CA 94720 USA

2001

LBNL-48242B

Multi-Project Baselines For CDM Projects: Case Study For The Cement Industry In China

Table of Contents

Multi-Project Baselines for CDM Projects:
Case Study for the Cement Industry in China

Yanjia Wang
US/China Energy and Environment Technology Center, Tsinghua University

Abstract

Using the methodology of multi-project baseline for CDM projects developed by the Lawrence Berkeley National Laboratory (USA), a case study for the cement industry in China was conducted. Data for six kilns were collected for the baseline calculation. Five hypothetical CDM projects were used for testing the methodology.

This paper presents the result of the analysis. It shows that the methodology requires some modifications based on China's data situation. Instead of plant-based baselines as originally envisioned, kiln-based baselines are more appropriate for China. Specifically, kilns with advanced domestic technology should be used for the baseline calculation. Then, in order to meet the requirement of additionality, CDM projects must adopt imported advanced technologies in China. Mitigation can be achieved through fuel reduction in the kiln and electricity efficiency improvement**.** Fuel switching from coal to other low-carbon fuels can increase CO_2 reductions. Other measures besides energy-efficiency improvement, such as blending, should be included in cement CDM projects

1. Introduction

From the perspective of carbon dioxide (CO_2) emissions, the cement industry is an unique special sector that emits CO_2 not only from energy consumption, but also from the production process (raw materials). The level of emissions from the production process is almost same as that from energy consumption. China is the largest cement producer and consumer in the world. CO_2 mitigation can be achieved in the cement industry through energy-efficiency improvement as well as through cement utilization reduction, which includes such measures as increasing cement utilization efficiency, reducing clinker consumption for cement production, and replacing cement by other materials for construction.

In December 1997, the third Conference of the Parties (COP3) to the United Nations Framework Convention on Climate Change (UNFCCC) was held in Kyoto. Industrialized countries (i.e. Annex 1 countries) agreed to reduce their greenhouse gas (GHG) emissions, in the 2008-2012 commitment period, by at least 5% below 1990 levels. In order to reduce the cost of mitigation, Article 12 of the Kyoto Protocol makes provisions by which those signatories who are required to limit emissions can gain credit for financing cost-effective mitigation projects in developing countries, while at the same time promoting sustainable development through the provision of financial and technical assistance. The Clean Development Mechanism (CDM) is one of three flexibility mechanisms for emission reductions that were adopted as part of the Kyoto Protocol.

Additionality is the first measurement to judge a project qualifying under the CDM. There are several prerequisites associated with the determination of a CDM project'semission reduction levels, such as project boundaries, in which the definition of baseline plays an important role for evaluating a CDM candidate project.

The cement industry is a favorable sector for CDM implementation. In general, there is a large potential for energy-efficiency improvement in China because most of the cement plants use outdated technology and equipment. But there are numerous large-scale plants now adopting advanced technology and using imported equipment. The performance and energy efficiency of these plants are much better than the average Chinese cement plant.

If CDM is implemented in the future, the candidate project selection in the cement industry will heavily depend on the baseline calculation. For this case study, we use data from six large-scale plants to construct a multi-project baseline. This baseline calculation indicates that the CDM candidate projects should adopt international advanced technologies in order to meet the requirement of additionality. Domestic technologies only can beat an average multi-project baseline.

2. Background of the Cement Industry in China

China's first cement plant was built in 1889, just 18 years after the first Portland cement plant in the U.S. started operation. Since then, China's cement output has increased continuously. Growth in cement production was very fast, especially during the last two decades. In 1985, China became the largest cement producer in the world. Now China's cement output accounts for more than one third of total worldwide. From the following tables, one can follow the development trajectory of the country's cement industry and its characteristics.

2.1 Fast growth rate of cement production

Table 1 shows the cement output and its growth rate. Cement production in China grew at an average rate of about 10% from 1980 to 1999, higher than that of the gross domestic product (GDP) (about 9.4%).

Table 1. Cement production in China, 1950-1999 (million tons)

Year	Cement output	Annual growth rate (%)	Year	Cement output	Annual growth rate (%)
1950	1.41		**1989**	210.29	0.0
1960	15.65	27.2	**1990**	209.71	-0.0
1970	25.75	5.1	**1991**	252.61	20.5
1980	79.86	12.0	**1992**	308.22	22.0
1981	82.90	3.8	**1993**	367.88	19.4
1982	95.20	14.8	**1994**	421.18	14.5
1983	108.25	13.7	**1995**	475.61	12.9
1984	123.02	13.6	**1996**	491.19	3.3
1985	145.95	18.6	**1997**	511.74	4.2
1986	166.06	13.8	**1998**	536.00	4.7
1987	186.25	12.2	**1999**	573.00	6.9
1988	210.14	12.8			

Source: State Statistical Bureau, 2000

2.2 Rapid increase of small cement plants

Because of the high demand, many small-scale cement plants were built through township and village enterprises. At the end of 1997, there were 8435 cement plants with a total capacity of 660 million tons of clinker per year. There were only 576 large-scale plants with an annual output larger than 200,000 tons each. To date, China only has 17 kilns with a capacity larger than 3000 tons of clinker per day. The largest is 7200 tons per day in the Dayu Cement Plant that was jointly constructed with a foreign company. Kilns with capacities of 700, 1000 and 2000 tons per day number 36, 27 and 29, respectively. There are 5115 small-scale plants with annual outputs of 50,000 tons and below. These small-scale plants have low product grades, low productivity, and are energy- and pollutant-intensive. In 1998, the State Council decided to shut down 4247 small cement plants with 5063 kilns and capacities of 1000 million tons in 1999 and 2000 to restructure the cement industry, reduce energy consumption, protect local environment and control total output. Tables 2 and 3 show China's cement industry production mix by plant size.

Most cement plants have several small capacity kilns. Some plants keep the small kilns running even after they have constructed a new large-scale kiln. Table 4 shows the difference in capacity per kiln between China and Japan.

Table 2. China's cement production mix by plant size

Year	Total cement output (Mt)	Production by large-medium size plants (Mt)	Proportion of large-medium size plants (%)
1960	15.65	11.01	70.35
1965	16.34	11.06	67.69
1970	25.75	15.17	58.91
1975	46.26	19.09	41.27
1980	79.86	25.58	32.03
1985	159.55	32.35	20.28
1990	209.71	39.86	19.01
1997	511.74	75.40	14.73
1998	536.00	88.40	16.49
1999	573.00	115.60	20.17
2000 (estimated)	576.00	203.90	35.40

Source: State Statistical Bureau, 1992; State Statistical Bureau, 2000.

Table 3. Cement production by kilns in China (1999)

Kiln type	Units	Capacity (tons/d-set)	% total cement output
NSP kiln (large scale)	109	700-7200	8.3
NSP kiln (small scale)	96	300-600	1.1
Preheater kiln (large)	3	800-1000	0.1
Preheater kiln (small)	72	100-300	0.3
Preheater vertical	295	200-400	1.8
Semi-dry	9	700-2000	0.6
Inner hollow kiln	109	500-1000	2.0
Libor kiln	20	400-600	0.5
Wet rotary kiln	206	400-800	6.1
Vertical kiln	12000	50-350	77.7
Total	13259		100.0

Source: *China Building Material* No. 5, 2000

Note: NSP kilns are the most efficient kilns and have both suspension preheaters and precalciners.

Table 4. Comparison of annual capacity per kiln between China and Japan

	Year	China	Japan
Number of kilns	1987	2871	96
	1990	3912	81
	1997	about 14300	--
Annual capacity (k ton)	1987	204670	97221
	1990	268890	87808
	1997	660165	--
Average annual capacity per kiln (k ton)	1987	71	1013
	1990	69	1084
	1997	47	--

Source: *Cement No. 1, 1993*, *China Building Material* No. 5, 2000

2.3 Cement production satisfies domestic demand

Due to continued cement plant construction, China stopped importing cement in 1990. Cement production has been able to satisfy domestic demand even in recent years when the government has increased investment for infrastructure construction. Currently, China is a net exporter of cement. Considering the energy consumption and pollution issues, some developed countries have decreased domestic cement production and are now importing cement and clinker from China. For example, in 1998, about 2 million tons of cement and 200 thousand tons of clinker were exported from China to the U.S.

2.4 Low energy efficiency and unbalanced technology development

In general, the energy intensity of cement manufacturing in China is much higher than in developed countries. Table 5 shows the differences in specific energy consumption between China, Japan, and former West Germany. However, the complete situation in China is quite complicated because there are about 8000 plants. Table 6 shows the energy intensity for different kilns in China. It shows that the energy intensity of the best plant in China only reaches the world level of late 1980s.

Table 5. Comparison of specific energy consumption for cement production in Japan, former West Germany, and China

Country	Year	Heat intensity (MJ/ton clinker)	Elec. Intensity (kWh/ton cement)	Integrated energy intensity (MJ/ton cement)
Japan	1980 1990	3524 2947	124 102	3973 3311
Former West Germany	1980 1990	3219 2625	104 104	3592 3001
China (large and medium size plant)	1980 1990	6040 5433	97 110	6120 5990

Source: State Administration of Building Material Industry of China, 1992

Table 6. Energy intensity by kilns in China (1999)

Kiln type	Energy intensity (MJ/ton clinker) Average/Best		Electricity Intensity (kWh/ton cement) Average/Best	
NSP kiln (large scale)	3427	3135	115	105
NSP kiln (small scale)	4598	3762	130	115
Preheater kiln (large)	4640	3887	125	120
Preheater kiln (small)	4891	4389	125	120
Preheater vertical	4974	4598	125	120
Semi-dry	3846	3553	105	100
Inner hollow kiln	7106	6604	120	110
Libor kiln	4723	4159	120	115
Wet rotary kiln	6124	5768	105	95
Vertical kiln	5500	3658	115	67

Source: *China Building Material* No. 3, 2000.

2.5 Coal as the main fuel

Cement production uses only coal as the kiln fuel in China. Coal accounted for 80% of total cement production energy consumption. Because coal-fired power plants generate almost four-fifths of total electricity in China, the carbon intensity for cement production is much higher than other countries. Table 7 shows the energy consumption of cement production in China.

Table 7. Energy consumption of cement industry in China

Year	**1990**	**1995**	**1997**
Cement output (Mt)	210	476	513
Energy consumption (Mtce)	410.71	87.28	93.21
Of which:			
coal (Mtce)	32	68	73
elec.(GWh)	21370	47600	49200
oil (k ton)	150	--	--

Source: *China Energy* No.7, 2000.

2.6 CO_2 emissions

From the perspective of CO_2 emissions, the cement industry is a special sector that emits CO_2 from both energy consumption and the production process. It is estimated that the cement industry emitted 43.33 million tons of CO_2 (in tC) in 1990 of which 50% was from the production process and 50% was from energy consumption. In 1997, emissions reached 102 million tons of CO_2 (tC).

There are several studies conducted by Chinese researchers on CO_2 emissions from non-energy activity in the cement industry. These studies have a slightly different emission factor due to the use of different data. One study indicated that one ton of clinker contains 0.62 tons of CaO, and one ton of cement consumes 0.75 tons clinker (*China Energy*, No 7, 2000). Thus, the emission factor is: 0.62* (44/56) * 0.75 = 0.3654 ton-CO_2/ton cement.

Another study indicated that one ton of clinker consumes 1.157 ton $CaCO_3$ and one ton of cement requires 0.739-ton clinker. The emission factor is: 1.157 * (44/100) * 0.739 = 0.3762 ton-CO_2/ton cement (Research Team of the China Climate Change Country Study, 1999).

The difference in CO_2 emissions from energy use in the cement industry mainly comes from its electricity consumption. If CO_2 emissions from electricity consumption are included as part of total emissions from the cement industry, then the different sources of power generation should be considered. Emission data for the cement industry in China typically are only the emissions from fuel consumption, excluding electricity consumption. Table 8 shows the estimated CO_2 emissions from the Chinese cement industry.

2.7 Development target

In order to improve energy efficiency and reduce the various emissions from cement plants, the Chinese government plans to limit total cement output to no more than 600 million tons per year. There will be a focus on restructuring the cement industry by replacing small-scale cement plants by large-scale NSP kilns with high efficiency. In 1999 and 2000, there were 4247 small cement plants in which 5063 kilns were closed. Now, newly built kilns must be larger than 4000 tons/day in the east coast areas and 2000 tons/day in the central and western areas. It is planned that at the end of years 2005 and 2020, 110 and 450 million tons of cement will be produced by NSP kilns, accounting for 20% and 75% of total output of each year, respectively. NSP kilns produced 8.3% of total cement output in 1997.

Table 8. CO_2 emissions of the cement industry (million tons C)

Year	1990	1995	1997
From fuel consumption	22.46	47.63	51.32
From process	20.87	47.38	51.04
Total emission	43.33	95.01	102.37

Source: *China Energy* No.7, 2000

3. Multi-Project Baselines for Cement Production

3.1 Data availability

During the past two decades, supported by domestic commercial banks, the Asian Development Bank, the World Bank, and other financial sources, some cement plants introduced advanced technologies and equipment to retrofit their plants. Even so, most of the plants kept their old kilns for production. There are two reasons for keeping the old kilns running: first, cement sales were high and second, the jobs were needed.

Thus, these plants have two or three generations of kilns such as wet process kilns, vertical kilns and NSP kilns. In order to represent the best available technology, all data we collected are based on the newest generation of kiln in the plants. These kilns have run for several years with steady operation. These kilns represent the present situation of advanced technology of the cement industry in China.

Data for six kilns were collected from six cement plants. These plants are located nation-wide. They consume various kinds of coal and electricity from different power grids. There are eight independent power grids in China. The sources for power generation are quite different. Some grids include more hydropower than others. According to statistics, 1080 TWh of electricity was generated in 1996, in which 17% was hydropower, 1% nuclear and 82% thermal as shown in Figure 1, Table 9 and Figure 2 show the fuel consumption for thermal power plants in 1996. In order to simplify the multi-project baseline calculation, the national-level fuel mix for electricity generation was used to calculate the carbon content of electricity for this analysis. The electricity carbon content in China is much higher than those countries that use more hydro and low carbon content fossil fuel such as natural gas and fuel oil for power generation. Electricity efficiency improvement is an important measure for CO_2 reduction in the cement industry in China.

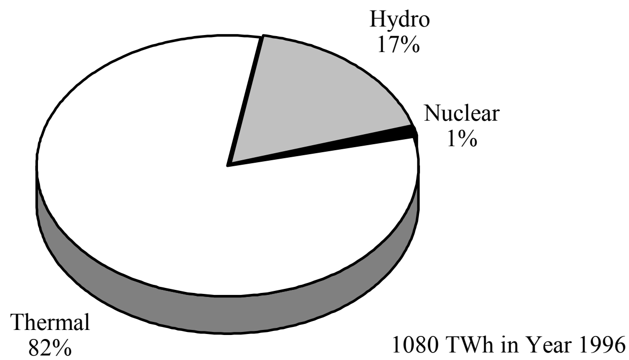

Figure 1. Power generation mix

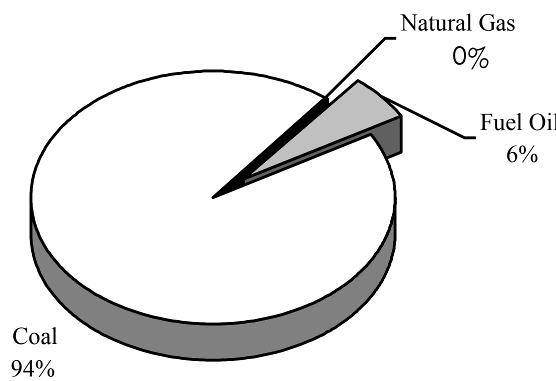

Figure 2. Thermal power fuel mix

Table 9. Fuel mix for power generation (1996)

Coal	8913	PJ
Natural Gas	338	PJ
Fuel Oil	438	PJ
Electricity	1080	TWh
Carbon content	0.226	kg C/kWh

Source: State Statistical Bureau, 1998.

Six types of data are needed for the multi-project baseline calculation. They are:

1 - annual throughput at raw materials grinding stage (Mtonne)
2 - annual electricity use for grinding raw materials (GWh)
3 - annual production of clinker (Mtonne)
4 - annual energy use of specific fuels for clinker production (GJ)
5 - annual throughput at cement grinding stage (Mtonne)
6 - annual electricity use for grinding cement (GWh)

In addition to the above data, four indicators are used to present the energy consumption and cement production situation in cement plants in China. They are:

1 - annual production of clinker (Mtonne)
2 - annual energy use of specific fuels for clinker production
3 - annual production of cement
4 - annual electricity use for whole production process

According to studies (Mohanty, 1997), the electricity consumption for the cement plant can be divided into three stages: raw material preparation (before kiln), clinker production (during kiln) and finishing (after kiln). Figure 3 shows the general situation of electricity consumption by process. One case study shows the mills for blending raw material, coal, clinker and cement consume 20.1 kWh per ton of raw material, 36.5 kWh per ton of coal, 31.5 kWh per ton of clinker and 32 kWh per ton of cement, respectively (NCDRI, 1994)). Comparing the data between Figure 3 and Table 10, it shows that the electricity consumption in raw material grinding stage in baseline calculation includes the consumption in first two stages. Converting the data the plant has to the data required for the baseline calculation is based on expert judgement.

Table 10. Six-baseline kilns energy and carbon intensity

Kiln No.	**1**	**2**	**3**	**4**	**5**	**6**
Capacity (t clinker/day)	4000	4000	2000	2000	4000	2000
Energy	Coal & Electricity					
Raw Material Grinding Stage						
Energy intensity (kWh/tonne)	68.81	66.67	70.19	69.06	70.64	73.04
Carbon intensity (kg C/tonne)	15.55	15.07	15.86	15.61	15.97	16.51
Clinker Production Stage						
Energy intensity (GJ/tonne clinker)	3.37	3.28	3.03	3.77	3.13	3.77
Carbon intensity (kg C/tonne clinker)	88.80	86.35	79.89	99.25	82.46	99.29
Cement Grinding Stage						
Energy intensity (kWh/tonne cement)	40.50	32.45	45.20	39.47	33.00	42.49
Carbon intensity (kg C/tonne cement)	9.15	7.33	10.22	8.92	7.46	9.60

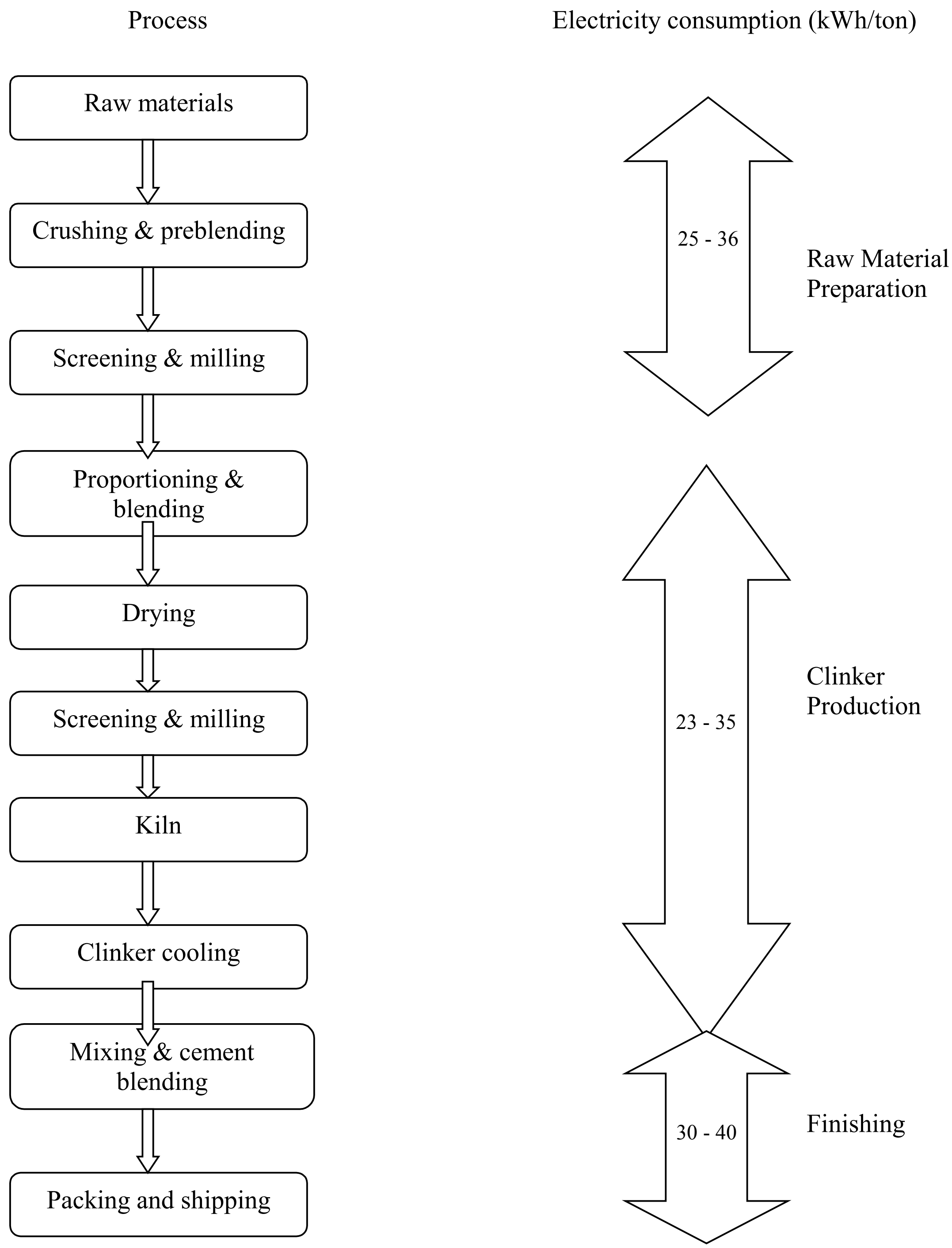

Figure 3. Electricity consumption by process

3.2 Multi-project baseline calculation

Based on the data for the six kilns, the baseline intensities were calculated as shown in Table 11 and Figure 4. We analyzed five different multi-project baselines based on the average performance of the kilns in our sample, the weighted average performance, the 25th percentile, the 10th percentile, and the best plant. Because of the small number of plants used for the multi-project baseline calculation, the baseline intensity of the 10th percentile is the same as that of the best plant. This illustrates that the benchmark is heavily dependent upon the kiln data used. Which kilns are selected is very important for the benchmark calculation. Among the six kilns, three kilns are imported and have capacities of 4000 tons per day. The others are domestically made with capacities of 2000 tons per day. There is no plant that is the best at all three stages.

The carbon intensity of the clinker production stage is much higher than the other stages. The carbon intensity by electricity consumption (both in raw material grinding and cement grinding) is about one fifth of clinker production. Up to now, coal is the only fuel used for clinker production kilns in China. There is no difference in fuel-specific and sector-wide calculations.

Table 11. Baseline intensity

	Benchmark Basis:	**Average**	**Weighted Average**	**Percentile 25%**	**Percentile 10%**	**Best Plant**
Raw Material Grinding Stage						
carbon intensity	kg C/tonne	15.76	15.71	15.17	15.07	15.07
Clinker Production Stage						
carbon intensity	kg C/tonne	87.47	85.92	79.22	78.22	78.22
Cement Grinding Stage						
carbon intensity	kg C/tonne	8.78	8.72	7.36	7.33	7.33

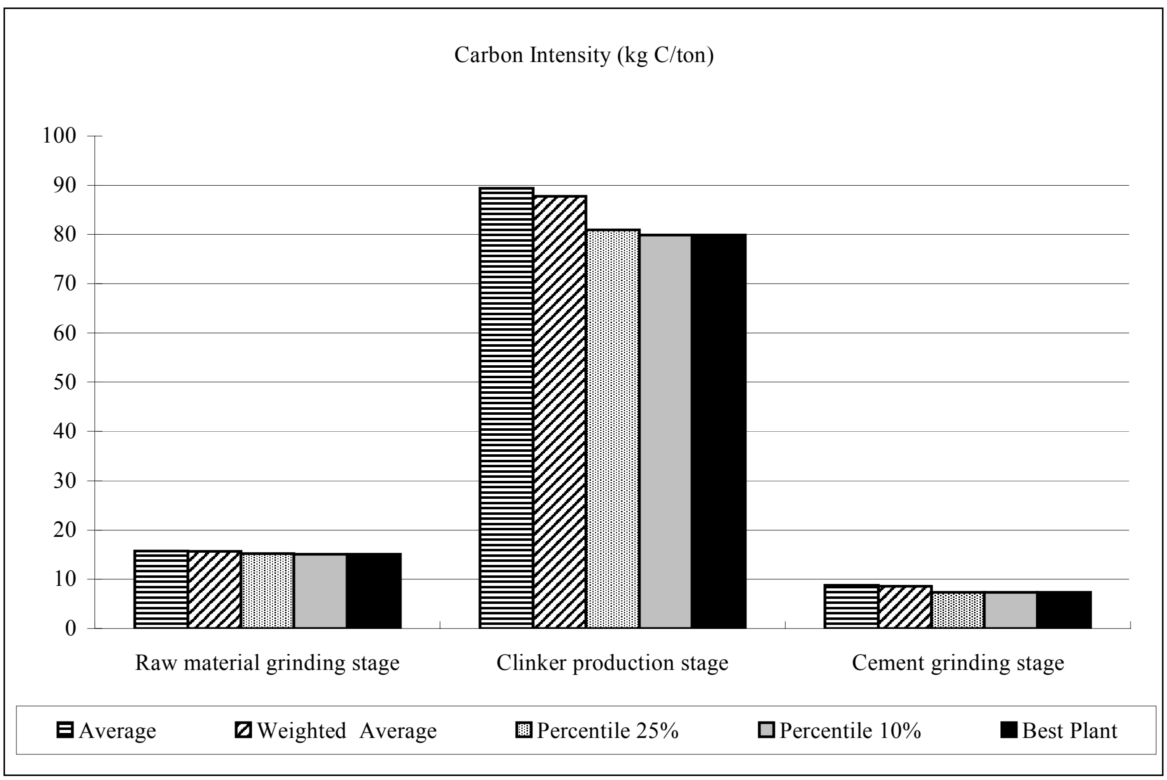

Figure 4. Baseline Intensity

4. Assessment of Hypothetical Cement CDM Plants

The objective of this analysis is to test the use of a multi-project baseline for CDM candidate project assessment. Based on the following considerations, five hypothetical projects were selected for CDM project implementation. Table 12 provides the energy intensity values for these five projects.

Projects #1 and #3 will adopt advanced domestic technology with the capacity of 4000 tons per day. Project #3 has higher electricity efficiency than Project #1 for testing the impact delivered by electricity-efficiency improvement. Projects #2, #4 and #5 will adopt imported technology with the capacity of 7200 tons per day. Different fuels will be used in these three projects for testing the impacts of fuel switching. Table 12. Energy intensity for the five hypothetical CDM projects

PLANT NAME		**Project 1**	**Project 2**	**Project 3**	**Project 4**	**Project 5**
Capacity (ton/day)		4000	7200	4000	7200	7200
Hypothetical		Advanced domestic technology	Imported technology	Domestic technology combined with electricity efficiency improvement	Imported technology and mix fuel (50% coal and 50% NG)	Imported technology and fuel switch (100% NG)
Raw Material Grinding Stage						
energy intensity	kWh/ton	64.00	46.00	46.10	46.00	46.00
Clinker Production Stage						
energy intensity	GJ/ton	3.13	3.00	3.13	3.00	3.00
Cement Grinding Stage						
energy intensity	kWh/ton	35.00	30.00	30.10	30.00	30.00

Table 13 provides information on NSP kilns. NSP kilns are the most efficient kilns currently available and have both suspension preheaters and precalciners. In general, larger scale kilns have higher fuel efficiency and lower investment intensity, as shown in Table 13. The largest existing kiln in China is 7200 tons/day. It is assumed that kilns of 7200 tons/day or larger will be imported in the future.

In order to reduce the cost, many studies have been conducted in order to be able to produce the imported equipment domestically. China can now make most of components of a 4000-ton/day kiln. The Chinese government now expects the 4000 tons/day kilns to be the main size of kilns for new construction. In the east cost areas, the more developed areas in China, new kilns must be 4000 tons/day or larger. Many 4000 ton/day kilns will be built to replace the old small-scale kilns in the near future.

Although electricity is a small part of energy consumption during the cement process, improving electricity efficiency is valuable to reduce carbon emissions because coal-fired power plants are the main facilities for generation in China. Two hypothetical CDM projects are considered based on different electricity efficiencies and the same fuel efficiency.

Currently, coal is the only fuel used in kilns. As the natural gas resource is developed, especially the “west–to-east” natural gas project that will be completed in 2003, it will be possible to replace coal by natural gas for cement production. Two CDM projects present the fuel switching situations, one is replacing 50% coal by natural gas and the other is using 100% of natural gas.

Table 13. NSP kiln characteristics by size

NSP kiln capacity (t/d)	**4000**	**2000**	**1000**
Percentage of domestic made equipment (%)	80-90	90	100
Investment (US $/ton cement)	60-65	65	65
Energy intensity (kJ/kg clinker)	3093-3153	3153-3177	3302-3428
(kWh/t cement)	98	100	105

Table 14 shows the carbon intensity of the five hypothetical CDM projects. It shows that comparing Projects #1 and #2, as the capacity scale is increased, the fuel and electricity efficiency improves, and the carbon intensities decrease in different stages. Carbon emission reduction can also be achieved by improving electricity efficiency only, as in Projects #1 and #3. The largest carbon emission reductions can be gained by using clean energy. The more low-carbon fuel used, the more mitigation achieved (see Projects #2, #4 and #5).

Table 14. Carbon intensities of five hypothetical CDM projects

PLANT NAME		**Project 1**	**Project 2**	**Project 3**	**Project 4**	**Project 5**
Capacity (ton/day)		4000	7200	4000	7200	7200
Raw Material Grinding Stage						
carbon intensity	kg C/ton	14.46	10.40	10.42	10.40	10.40
Clinker Production Stage						
carbon intensity	kg C/ton	80.75	77.40	80.75	61.65	45.90
Cement Grinding Stage						
carbon intensity	kg C/ton	7.91	6.78	6.80	6.78	6.78

5. Results

Table 15 compares the performance of hypothetical CDM projects against different multi-project baselines. A positive number indicates that the hypothetical CDM project has lower carbon intensity than the baseline. The larger the number, the better the performance in terms of carbon intensity. Only projects with positive values are viable CDM projects.

Present domestic advanced technology, as represented by Project #1, can only beat the average benchmark. If better-than-average benchmarks are used, there are no energy savings or carbon savings for these plants in either the fuel-specific or sector-wide cases. Domestic advanced technology with additional electricity-efficiency improvements, as represented by Project #3, are better than all of the benchmarks from a total plant point of view, although the carbon reduction of clinker production is lower than the better-than-average benchmarks. This means that electricity efficiency is an important reduction measure because of the reliance on coal as the main source for power generation. This conclusion is made based on the nation-wide power source mix; for some areas where more hydropower is used for electricity production, there may be no carbon reduction benefits through electricity-efficiency improvement.

Imported advanced technology, as represented by Project #2, is better than all of the benchmarks.

Huge carbon reduction benefits can be gained if the plant uses more low-carbon fuel to replace coal. Fuel switching away from coal, as represented by Project #4 (50% coal and 50% natural gas) and Project #5 (100% natural gas), gives the largest carbon emission reductions. However, since coal is currently the only fuel used for kilns, we can't compare the CDM project to benchmarks from the fuel-specific point of view and only the sector-wide calculation is available.

6. Conclusions

Based on the analysis of five hypothetical CDM cement projects using a multi-project baseline approach, we have the following conclusions:

6.1 Methodology modification

There are two indicators currently used to measure the energy consumption or efficiency in cement plants in China. They are specific fuel consumption for clinker production and integrated electricity consumption for cement production. If the methodology developed by LNBL is used in China, we should change data collection requirement based on China's data situation. It is suggested that the following data be required for the baseline calculation.

1 - annual production of clinker (Mtonne)
2 - annual energy use of specific fuels for clinker production (GJ)
3 - annual production of cement (Mtonne)
4 - annual electricity use for whole production process (MWh)

6.2 Data availability

There is no database for the cement industry in China related to energy consumption. Data should be collected on a plant-by-plant basis, which is a time- and cost-consuming work. If the methodology is not changed for data collection as suggested above, it is very difficult to get data related to electricity consumption divided to different stages. Also, there is an absence of electricity consumption for kilns in the methodology.

6.3 Kiln-based baselines are appropriate for China

Some cement plants run several kilns, each with different efficiencies. For example, one plant selected for the baseline calculation runs four kilns: one vertical kiln, two wet process kilns and one NSP kiln. The performance and energy efficiency of these kilns are quite different. The general data from the plant usually presents the average performance, which hides the significant differences in efficiency. Thus, it is important that kiln-based data be collected for the baseline calculations.

6.4 Kilns for baseline calculations must be selected carefully

It is not simple to understand the kiln's technology levels based on its construction date in China. The technologies the plant adopted depend on financial resources. The domestic, cheaper but not state-of-the-art technologies will be adopted by those plants with limited funds. Normally, the projects supported by international financial organizations or listed in the official key project construction plan, have sufficient funds and can adopt international advanced technologies. The performance of these plants is better than the plants under construction or even planned plants. On the other hand, due to management, personal capacity and mastering know-how, the performance of similar kilns can be quite different in different plants. Some old kilns run better than the newly-built kilns. Which kilns should be used for establishing multi-project baseline is an important topic for further research. The better the kilns' data (kilns with higher energy efficiency) we adopt for calculation, the lower the carbon intensity the baseline has. If the baseline has very low carbon intensity, there will be a few candidate projects that can meet the additionality criterion.

The data from kilns with advanced domestic technology level should be collected for the baseline calculation because a CDM project should benefit non-Annex 1 countries in terms of technology, capital and know-how transfer. If we use the data from imported advanced kilns, it is unlikely that any CDM projects will occur.

Another area to evaluate is how many kilns will be used for the baseline calculation. If only ten or fewer kilns are used for the calculation, there is no difference between 10% percentile and best plant baseline.

6.5 CDM projects should adopt international advanced technologies

In order to meet the requirement of additionality, CDM projects must adopt imported advanced technologies that can beat all benchmarks according to the baselines established in this research. The projects adopting advanced domestic technology can beat only the average and weighed average baselines. The question is if a CDM project is implemented that adopts international advanced technologies, shall we calculate the baseline again using the new data? If we do, the best plant must represent the new kiln and no other kilns will then be able to beat the best plant baseline.

There are only six kilns' data for baseline calculation. This is not enough for commenting on which baseline level we should adopt for evaluating a CDM candidate project. In general, a 10% percentile baseline may be good for CDM project evaluation because it can eliminate the outliers in data collecting. At the same time, it can identify the present advanced technology of non-Annex 1 countries and assist in realizing technology transfer.

6.6 Mitigation can be achieved through fuel reduction in the kiln and electricity efficiency improvement

There is no doubt that carbon emissions can be reduced through improving fuel efficiency in the kiln. Since coal is the main source of power generation, there is an associated carbon reduction through electricity-efficiency improvement. But when we analyze CO_2 emissions by sector, the emissions from power generation are typically included in the power industry. The cement industry emission data used above do not include the indirect emissions from electricity consumption.

6.7 Fuel switching from coal to other low-carbon fuel can increase CO_2 reductions

Using low-carbon fuel for kilns and power generation can increase CO_2 reductions. The issue is how to develop low-carbon resources and markets. For example, after the west–to-east natural gas project is completed, it can supply 12 billion cubic meters of natural gas to Shanghai, the more developed area in China. The price of natural gas is estimated to be 0.16 US$ per cubic meter which is higher than in most developed countries. The industries, however, want to pay 0.13 US$ per cubic meter. Overcoming such barriers to promote natural gas utilization is currently a big topic in China.

6.8 Other measures besides energy efficiency improvement should be included in cement CDM projects

The cement industry is one of a few sectors that emit CO_2 not only from energy consumption but also from the production process. The emissions from the production process are almost equal to those from energy consumption. Improving energy efficiency can only solve part of problem. Reductions in cement utilization or in the clinker consumption for cement production are effective measures for CO_2 reduction. For example, some kinds of slag from the metallurgical industry have special characteristics that can blend with clinker to produce cement and improve the quality of cement. According to a rough estimate, if the cement output target is 600 million tons per year in the next two decades, 1% more slag will be used for cement production than is currently used and as a result 0.8 million ton-C of CO_2 will be reduced from clinker production process. CDM should also pay attention to such measures.

Acknowledgments

This paper contributes to a larger research effort co-ordinated by the Lawrence Berkeley National Laboratory (LBNL). Similar studies are also being conducted in Brazil, India and South Africa. LBNL is supporting the presentation of the results of this paper to the sixth Conference of the Parties (COP-6) to the UN Framework Convention on Climate Change, held in The Hague, Netherlands from 13 – 25 November 2000.

References

Cement No. 1, 1993

China Building Material No. 3, 2000.

China Building Material No. 5, 2000.

China Energy No.7.

Mohanty, B. (ed.), 1997, Technology, energy efficiency and environmental externalities in the cement industry, Asian Institute of Technology, 1997 ISBN 974-8256-70-7

NCDRI (1994) Feasibility Study Report for Technical Retrofitting Engineering of Huaxin Cement Ltd. Co.

Research Team of China Climate Change Country Study, China Climate Change Country Study, Tsinghua University Press, 1999 ISBN 7-302-03404-4/P.1

State Administration of Building Material Industry of China, 1992. Document.

State Statistical Bureau, 1992. Statistical Yearbook of Building Material Industry 1991. Beijing: China Statistical Publishing House.

State Statistical Bureau, 1998. China Energy Statistical Yearbook (1991-1996). Beijing: China Statistical Publishing House.

State Statistical Bureau, 2000. Statistical Yearbook of China, 2000. Beijing: China Statistical Publishing House.

UNFCCC, 1997. Kyoto Protocol to the United Nations Framework Convention on Climate Change, Document FCCC/CP/1997/7/Add.1

Zhu, 2000. “GHG emission and mitigation in cement industry,” China Energy No.7.

Table 15. Decrease in carbon intensity from CDM projects against baselines

Project #1			Energy/carbon reductions relative to various benchmarks *(project performs this much lower than benchmark)*				
PROCESSES:		**Project Performance**	Average	Weighted Average	Percentile 25%	Percentile 10%	Best Plant
Raw Material Grinding							
energy intensity	kWh/tonne	64	5.73	5.5	3.1	2.67	2.67
carbon intensity	kg C/tonne	14.46	1.3	1.24	0.7	0.6	0.6
Clinker Production							
Fuel-Specific							
energy intensity	GJ/tonne	3.13	0.26	0.2	-0.06	-0.1	-0.1
carbon intensity	kg C/tonne	80.75	6.72	5.17	-1.53	-2.53	-2.53
Sector-Wide							
energy intensity	GJ/tonne	3.13	0.26	0.2	-0.06	-0.1	-0.1
carbon intensity	kg C/tonne	80.75	6.72	5.17	-1.53	-2.53	-2.53
Cement Grinding							
energy intensity	kWh/tonne	35	3.85	3.59	-2.44	-2.55	-2.55
carbon intensity	kg C/tonne	7.91	0.87	0.81	-0.55	-0.58	-0.58
PLANT TOTAL:							
Fuel-Specific							
Energy Savings	TJ		517.2	433.2	None	None	None
	GJ/tonne cement		0.38	0.31	None	None	None
Carbon Savings	Ktonne		12.4	10.2	None	None	None
	kg C/tonne cement		8.97	7.43	None	None	None
Sector-Wide							
Energy Savings	TJ		517.2	433.2	None	None	None
	GJ/tonne cement		0.38	0.31	None	None	None
Carbon Savings	Ktonne		12.4	10.2	None	None	None
	kg C/tonne cement		8.97	7.43	None	None	None

Table 15. Decrease in carbon intensity from CDM projects against baselines (continued)

Project #2			***Energy/carbon reductions relative to various benchmarks*** *(project performs this much lower than benchmark)*				
PROCESSES:		**Project Performance**	Average	Weighted Average	Percentile 25%	Percentile 10%	Best Plant
Raw Material Grinding							
energy intensity	kWh/tonne	46	23.73	23.5	21.1	20.67	20.67
carbon intensity	kg C/tonne	10.4	5.36	5.31	4.77	4.67	4.67
Clinker Production							
Fuel-Specific							
energy intensity	GJ/tonne	3	0.39	0.33	0.07	0.03	0.03
carbon intensity	kg C/tonne	77.4	10.07	8.52	1.82	0.82	0.82
Sector-Wide							
energy intensity	GJ/tonne	3	0.39	0.33	0.07	0.03	0.03
carbon intensity	kg C/tonne	77.4	10.07	8.52	1.82	0.82	0.82
Cement Grinding							
energy intensity	kWh/tonne	30	8.85	8.59	2.56	2.45	2.45
carbon intensity	kg C/tonne	6.78	2	1.94	0.58	0.55	0.55
PLANT TOTAL:							
Fuel-Specific							
Energy Savings	TJ		1686.6	1567.8	902.9	817.8	817.8
	GJ/tonne cement		1.22	1.14	0.66	0.59	0.59
Carbon Savings	Ktonne		38.4	35.4	19.3	17.2	17.2
	kg C/tonne cement		19.76	18.22	9.94	8.86	8.86
Sector-Wide							
Energy Savings	TJ		1686.6	1567.8	902.9	817.8	817.8
	GJ/tonne cement		1.22	1.14	0.66	0.59	0.59
Carbon Savings	Ktonne		38.4	35.4	19.3	17.2	17.2
	kg C/tonne cement		19.76	18.22	9.94	8.86	8.86

Table 15. Decrease in carbon intensity from CDM projects against baselines (continued)

Project #3			***Energy/carbon reductions relative to various benchmarks*** *(project performs this much lower than benchmark)*				
PROCESSES:		**Project Performance**	Average	Weighted Average	Percentile 25%	Percentile 10%	Best Plant
Raw Material Grinding							
energy intensity	kWh/tonne	46.1	23.63	23.4	21	20.57	20.57
carbon intensity	kg C/tonne	10.42	5.34	5.29	4.75	4.65	4.65
Clinker Production							
Fuel-Specific							
energy intensity	GJ/tonne	3.13	0.26	0.2	-0.06	-0.1	-0.1
carbon intensity	kg C/tonne	80.75	6.72	5.17	-1.53	-2.53	-2.53
Sector-Wide							
energy intensity	GJ/tonne	3.13	0.26	0.2	-0.06	-0.1	-0.1
carbon intensity	kg C/tonne	80.75	6.72	5.17	-1.53	-2.53	-2.53
Cement Grinding							
energy intensity	kWh/tonne	30.1	8.75	8.49	2.46	2.35	2.35
carbon intensity	kg C/tonne	6.8	1.98	1.92	0.56	0.53	0.53
PLANT TOTAL:							
Fuel-Specific							
Energy Savings	TJ		1016.5	932.5	462.7	402.7	402.7
	GJ/tonne cement		0.74	0.68	0.34	0.29	0.29
Carbon Savings	Ktonne		22.7	20.6	9.2	7.7	7.7
	kg C/tonne cement		16.48	14.94	6.69	5.61	5.61
Sector-Wide							
Energy Savings	TJ		1016.5	932.5	462.7	402.7	402.7
	GJ/tonne cement		0.74	0.68	0.34	0.29	0.29
Carbon Savings	Ktonne		22.7	20.6	9.2	7.7	7.7
	kg C/tonne cement		16.48	14.94	6.69	5.61	5.61

Table 15. Decrease in carbon intensity from CDM projects against baselines (continued)

Project #4			***Energy/carbon reductions relative to various benchmarks*** *(project performs this much lower than benchmark)*				
PROCESSES:		**Project Performance**	Average	Weighted Average	Percentile 25%	Percentile 10%	Best Plant
Raw Material Grinding							
energy intensity	kWh/tonne	46	23.73	23.5	21.1	20.67	20.67
carbon intensity	kg C/tonne	10.4	5.36	5.31	4.77	4.67	4.67
Clinker Production							
Fuel-Specific							
energy intensity	GJ/tonne	3	Flag 2	Flag 2	Flag 2	Flag 2	Flag 2
carbon intensity	kg C/tonne	61.65	Flag 2	Flag 2	Flag 2	Flag 2	Flag 2
Sector-Wide							
energy intensity	GJ/tonne	3	0.39	0.33	0.07	0.03	0.03
carbon intensity	kg C/tonne	61.65	25.82	24.27	17.57	16.57	16.57
			Flag 2 indicates that this project is not appropriate for fuel-specific evaluation				
Cement Grinding							
energy intensity	kWh/tonne	30	8.85	8.59	2.56	2.45	2.45
carbon intensity	kg C/tonne	6.78	2	1.94	0.58	0.55	0.55
PLANT TOTAL:							
Fuel-Specific							
Energy Savings	TJ						
	GJ/tonne cement						
Carbon Savings	Ktonne						
	kg C/tonne cement						
Sector-Wide							
Energy Savings	TJ		1686.6	1567.8	902.9	817.8	817.8
	GJ/tonne cement		1.22	1.14	0.66	0.59	0.59
Carbon Savings	Ktonne		66	63	46.9	44.8	44.8
	kg C/tonne cement		33.93	32.39	24.12	23.03	23.03

Table 15. Decrease in carbon intensity from CDM projects against baselines (continued)

Project #5			*Energy/carbon reductions relative to various benchmarks* (project performs this much lower than benchmark)				
PROCESSES:		**Project Performance**	Average	Weighted Average	Percentile 25%	Percentile 10%	Best Plant
Raw Material Grinding							
energy intensity	kWh/tonne	46	23.73	23.5	21.1	20.67	20.67
carbon intensity	kg C/tonne	10.4	5.36	5.31	4.77	4.67	4.67
Clinker Production							
Fuel-Specific							
energy intensity	GJ/tonne	3	Flag 2	Flag 2	Flag 2	Flag 2	Flag 2
carbon intensity	kg C/tonne	45.9	Flag 2	Flag 2	Flag 2	Flag 2	Flag 2
Sector-Wide							
energy intensity	GJ/tonne	3	0.39	0.33	0.07	0.03	0.03
carbon intensity	kg C/tonne	45.9	41.57	40.02	33.32	32.32	32.32
			Flag 2 indicates that this project is not appropriate for fuel-specific evaluation				
Cement Grinding							
energy intensity	kWh/tonne	30	8.85	8.59	2.56	2.45	2.45
carbon intensity	kg C/tonne	6.78	2	1.94	0.58	0.55	0.55
PLANT TOTAL:							
Fuel-Specific							
Energy Savings	TJ						
	GJ/tonne cement						
Carbon Savings	Ktonne						
	kg C/tonne cement						
Sector-Wide							
Energy Savings	TJ		1686.6	1567.8	902.9	817.8	817.8
	GJ/tonne cement		1.22	1.14	0.66	0.59	0.59
Carbon Savings	Ktonne		93.5	90.5	74.5	72.3	72.3
	kg C/tonne cement		48.11	46.57	38.29	37.21	37.21

LBNL-48242C

Potential Multi-Project Baselines in the Power Sector in the Eastern Region of India

Joyashree Roy and Sarmistha Das
Department of Economics
Jadavpur University, Calcutta 700 032

Jayant Sathaye and Lynn Price, Editors
International Energy Studies Group, Energy Analysis Department
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory
1 Cyclotron Road, MS 90-4000
Berkeley, CA 94720 USA

2001

LBNL- 48242C

Potential Multi-Project Baselines in the Power Sector in the Eastern Region of India

Table of Contents

Potential Multi-Project Baselines in the Power Sector in the Eastern Region of India

Joyashree Roy and Sarmistha Das
Department of Economics
Jadavpur University, Calcutta 700 032

Abstract

Both developed and developing countries have good reasons to be concerned about climate change. The United Nations Framework Convention on Climate Change (UNFCCC) aims to reduce emissions of greenhouse gases (GHGs) in order to "prevent dangerous anthropogenic interference with the climate system" and promote sustainable development (UNFCCC 1992). The Kyoto Protocol, which was adopted in 1997, aims to provide the means to achieve this objective and thus goes beyond mere calls for action. Under the UNFCCC, both the developed and developing countries agreed to take measures to limit emissions and promote adaptation to future climate change impacts, submit information on their national climate change programmes and inventories, and to promote technology transfer, awareness, training.

Several mechanisms have been proposed to achieve emissions reductions globally under the Kyoto Protocol. The Clean Development Mechanism (CDM) is one of three 'flexibility mechanisms' in the Protocol, the other two being Joint Implementation (JI) and Emissions Trading (ET). These mechanisms allow flexibility for Annex I Parties to achieve reductions by extra-territorial as well as domestic activities. The underlying concept is that trade and transfer of credits will allow emissions reductions at least cost. The CDM allows Annex I Parties to meet part of their emissions reductions targets by investing in developing countries. CDM projects must also meet the sustainable development objectives of the developing country. Further criteria are that Parties must participate voluntarily, that emissions reductions are "real, measurable and long-term", and that they are additional to those that would have occurred anyway. The last requirement makes it essential to define an accurate baseline.

This paper suggests and works out an approach to demonstrate the use of a multiproject baselines approach for the setting of standardized baselines for the electric power sector. It illustrates the use of this approach by applying it to the eastern regional power grid in India.

1. Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) aims to reduce emissions of greenhouse gases (GHGs) in order to "prevent dangerous anthropogenic interference with the climate system" and promote sustainable development (UNFCCC 1992). The Kyoto Protocol, which was adopted in 1997 aims to provide means to achieve this objective. The Clean Development Mechanism (CDM)[1] is one of three "flexibility mechanisms" in the Protocol, the other two being Joint Implementation (JI) and Emissions Trading (ET). These mechanisms allow flexibility for Annex I Parties[2] to achieve reductions by international as well as domestic activities. The underlying concept is that trade and transfer of credits will allow for emissions reductions at least cost. Since the atmosphere is a global, well-mixed system, it does not matter where emissions are reduced. The CDM allows Annex I Parties to meet part of their emissions reductions targets by investing in developing countries. CDM projects must also meet the sustainable development objectives of the developing country. Further criteria are that parties must participate voluntarily, that emissions reductions are "real, measurable and long-term", and that they are additional to those that would have occurred anyway. The last requirement makes it essential to define an accurate baseline to project what would have occurred in the absence of the project.

2. Baselines and Additionality

Reductions of greenhouse gas emissions must be additional to business-as-usual. If a project would have happened anyway, it should not be a CDM project and should not receive investment through that mechanism. Once a project has qualified for the CDM and been implemented, the Certified Emissions Reductions need to be calculated. To do so, the difference between the projected baseline and the project's performance needs to be calculated.

Like any projection, baselines depend on assumptions about the future. Key assumptions include the level of economic growth, energy supply and demand, and the emissions assumed as a starting point.

The possibility that the determination of additionality may be separated from the calculation of credits has been discussed in the climate negotiations. Additionality may be tested by use of various "additionality screens", including environmental, financial, investment and technological additionality (UNFCCC 2000). The methodology for calculating baselines to determine credits may be separate. The purpose of this paper is to consider the calculation of baselines, rather than dealing explicitly with additionality.

3. Minimising Transaction Costs While Ensuring Environmental Integrity

The aim of multi-project baselines is to seek a balance between ensuring environmental integrity and minimising transaction costs. Setting project-by-project baselines would increase the transaction costs of CDM projects and thus reduce the number of projects that attract investment. The experience of the AIJ[2] pilot phase was that baselines are time-consuming and highly subjective. Hence, there have been suggestions to standardise baselines across many projects, to set them for particular sectors or given technologies. Multi-project baselines based on emissions

---

1 See Michael Grubb (1999) for a more detailed description of the CDM and its origin in the negotiations.

2 Activities Implemented Jointly. The AIJ pilot phase was initiated at the first Conference of the Parties to test the impact of implementing emissions reductions projects in some countries (developing countries or countries with economies in transition) and funded by others without generating credits.

intensity are known as benchmarks.[3] A concern about multi-project baselines is that they might undermine the environmental integrity, in that emission reductions might be credited that are not "real". The aim of this paper is to explore alternative options for multi-project baselines.[4]

Establishing a baseline for a particular activity, sector and/or region will potentially simplify the calculation of emissions reductions. Baselines need to be simple enough to be practical in developing countries. Various proposals for baselines are summarised in the Chairman's Draft Text on Mechanisms (26 October 2000) for the climate change negotiations. In bracketed text, it proposes that baselines for a CDM project should consider the lowest of:

a. "Existing actual emissions prior to the project;
b. The most reasonable economic technology for the activity;
c. Better-than-average current industry practice in the host country or an appropriate region; and
d. The [average] [top X per cent] for such an existing source in Parties included in Annex [I] [II]."
   (UNFCCC 2000, FCCC/SB/2000/Add.2: § 70)

While project-specific baselines may be costly, less stringent baselines pose a potential threat to the environmental integrity of the Protocol. If a multi-project baseline allows projects that would have occurred under business-as-usual, then free riders can claim credits for something that would have been created anyway. This threatens environmental integrity in that the project does not contribute to global emissions reductions. Under the CDM, both investor and host countries would have an incentive to inflate baseline emissions.

This paper considers a number of approaches to multi-project baselines for the electricity generation sector, and the implications for a set of hypothetical CDM projects in India.

4. Overview of the Power Sector in India

In India, primary energy production and consumption are dominated by coal. Tables 1 and 2 show this to be over 50%, with the remainder shared by nuclear, hydro, petroleum and natural gas.

Coal-based thermal generation dominates the electricity sector in India. Over the last 25 to 30 years, the capacity share of large hydro has declined, while that of nuclear power is growing slowly. The potential for hydro-power in India is 84,044 MW of which only 14.5% had been exploited by 1995. Hydro provided a substantial contribution in the 1970s but over time the balance has shifted to coal. The Indian power generation sector also includes a small amount of natural gas, hydro, nuclear, wind, solar, and biomass generation. India's ninth five-year plan (1997-2002) includes a target of 3,000 MW for non-hydro renewable capacity.

---

[3] See M. Lazarus *et al* (1999) for an evaluation of different approaches to benchmarking, and case studies of Argentina, China, South Africa, Thailand and the United States.

[4] This paper does not analyse the difference between multi-project baselines and a project-specific approach, a topic that warrants further attention.

Table 1. Production of Primary Sources of Conventional Energy in India (Petajoules)

Year	Coal & lignite	Petroleum	Natural gas	Electricity hydro & nuclear	Total
1970-71	1598	286	56	996	2936
1980-81	2491	440	91	1784	4806
1990-91	4063	1383	693	2800	8939
1999-2000	5503	1340	1095	3381	11319

Table 2. Consumption of Primary Sources of Conventional Energy in India

Year	Raw coal (000' tonnes)	Crude petroleum * (000'tonnes)	Natural gas (million cubic metres)	Electricity ** (MWh)
1970-71	71230	18379	647	43724
1980-81	109310	25836	1522	82367
1990-91	213360	51772	12766	190357
1998-99	313476(r)	68538	25716	313839
1999-2000(p)	329047	85964	26872	N.A.

(P)-Provisional (r)- Revised

* Crude oil in terms of refinery crude throughout.

** Includes thermal, hydro & nuclear electricity in utilities.

Source: Central Statistical Organisation, 2000.

At present thermal plants account for 72.9% of the total power generation, while the hydro and nuclear power plants contribute 15.2% and 2.5 % respectively. India's energy/GDP ratio has declined over time (Dasgupta and Roy, 2000). The average age of the thermal power stations in India is 30 years. The abundance of coal (India's coal reserve is 2000 billion tonnes) coupled with short construction periods (3-4 years for the smaller plants with capacity below 250 MW and 6-7 years for plants above 250 MW) has encouraged dependency on thermal power. But in spite of that, the plant load factor (PLF)-an important indicator of operational efficiency, is very low in India (average is approximately 65%). Although over the years various measures have been taken to achieve higher PLFs, they compare poorly with international levels. The average PLF for the eastern (43.7%) and north- eastern (17.9%) region are much lower than the All- India level. Besides, the use of low quality coal reduces the efficiency of the thermal power plants. Thermal efficiency varies across plants due to differences in grades of coal used and vintages of the plants. The coal use factor ranges from 0.53 kg/kWh to 0.88 kg/kWh .

Table 3. Installed Generating Capacity of Electricity in Utilities and Non-Utilities in India (MW)

Year	Utilities				Non-utilities			Grand Total
	Thermal	Hydro	Nuclear	Total	Railways	Self generating industries	Total	
1970-71	7906	6383	420	14709	45	1517	1562	16271
1980-81	17563	11791	860	30214	60	3041	3102	33316
1990-91	45768	18753	1565	66086	111	8502	8613	74699
1999-2000(p)*	71341	23816	2680	97837	165	15835	16000	113837r

(p)- Provisional * - From 1995-96 onwards, Thermal includes wind also.
MW = megawatt = Thousands kilowatt.
Non-utilities include private power generation, some of which is sold to the grid

Table 4. Gross Generation of Electricity in Utilities and Non-Utilities in India (GWh)

Year	Utilities				Non-utilities			Grand Total
	Thermal	Hydro	Nuclear	Total	Railways	Self generating industries	Total	
1970-71	28162	25248	2418	55828	37	5347	5384	61212
1980-81	61301	46542	3001	110844	42	8374	8416	119260
1990-91	186547	71641	6141	264329	29	25082	25111	289440
1999-2000 (p)*	386776	80637	13267	480680	25	49975	50000	530680

(p)- Provisional
* - From 1995-96 onwards, Thermal includes wind also.
GWh = gigawatt hour = Million kilowatt hours.

The high dependency on coal implies that India's electricity industry has relatively high GHG (CO_2) emissions. In addition, some methane is released during coal mining, production of coal and natural gas as well. With 237 million metric tons of carbon released from the consumption and flaring of fossil fuels in 1997, India ranked fifth in the world behind the United States, China, Russia and Japan.[5] So it can be expected that high power generation in India to satisfy the growing demand for electricity will increase the CO_2 emissions several-fold. It is very much important to note that low PLF of the thermal plants, high T&D losses and other operational and technical inefficiencies make the Indian power industry unable to take full benefit from its existing generating capacity.

[5] http://www.eia.doe.gov/emeu/cabs/indiaenv.html

To improve the operation of current plants as well as to increase total capacity, the Union government has announced the following objectives for future development in the power sector (Planning Commission, 1997):

- Raise efficiency, generation, safety, and reliability and reduce pollution of all the power plants.
- Introduce new efficient technology in retiring plants with the aim of reviving them.
- Conduct energy audits to reduce primary as well as secondary fuel consumption (through better plant maintenance).
- Renovate and refurbish existing units
- Adopt new hydro projects.
- Formulate mega-power projects in both private and public sector, which supply power to more than one state. These projects will be supported by power purchase security through power trading corporations for generating power at the lowest possible cost.
- Encourage private sector investment.

5. Ownership Pattern of the Indian Power Sector

Transmission and distribution are dominated by the government either through public sector undertakings (PSUs) or State Electricity Boards (SEBs). Public sector undertakings are defined as public-private partnerships in which the government has more than 50% share. Very few private licensees are currently engaged in power generation and supply. In 1999, the Union government allowed private sector participation in power transmission and distribution. Now private enterprises can set up units either as licensees – distributing power to the licensed area from their own generation, or as generating companies – generating power to supply to the grids. At present more than 95.6% of the generating capacity is government owned and 4.4% is under the private sector. The following figure highlights the current structure of the electricity supply industry in India.

For integrated operation of the power system, the electricity distribution network in India is divided into several regions: North, West, South, East and Northeast. We focus on the Eastern region in this analysis. The Eastern region covers three states – West Bengal, Bihar and Orissa. Though public, private, and government-owned public sector undertakings (PSUs) are all engaged in power generation, transmission and distribution, the power industry in this region is dominated by the PSUs. Total installed capacity in this region is 16,973 MW which is 15% of the total installed capacity of the country. Six PSUs in this region own 57% of the total regional power-generation capacity. The public sector owns Calcutta Electric Supply Corporation (CESC), the only private licensee in this region, owns 29% and the remaining 14% of generation capacity. Like other regions, the regional power grid in the eastern region, governed by the Eastern Regional Electricity Board (EREB), facilitates flows of power from surplus to deficit areas and assists in the optimum utilization of the power available. Total consumption in this region in 1999-2000 was 46,165 megawatt hours (MWh). In 1998-1999, the Eastern region exported 3,628 MWh to the neighboring region, which was 40% higher than the previous year.

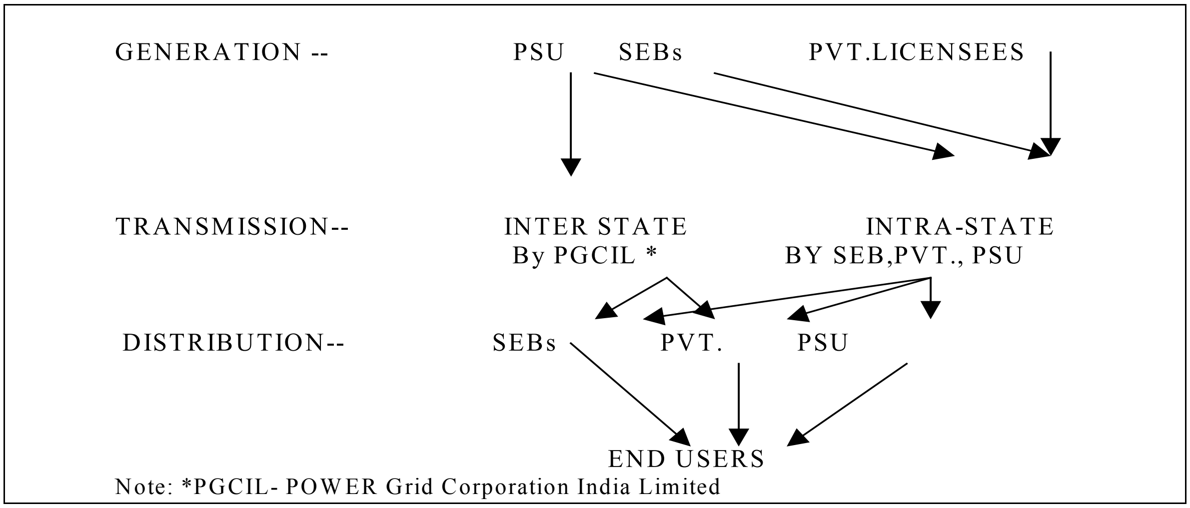

Figure 1. Current Structure of the Electricity Supply Industry in India

6. Characteristics of the Eastern Regional Grid Area

Regional electricity generating capacity is based on three primary resources: coal, oil, and hydro. The coal reserve of eastern region is the highest in India. The availability of coal encouraged the establishment of thermal power stations in this region at a greater rate. In spite of this, the Eastern region ranks fourth in thermal power generation among all regions in India. Although most of the thermal plants are owned and operated by PSUs (National Thermal Power Corporation, NTPC, Damodar Valley Corporation, DVC, GRIDCO) and SEBs (Bihar State Electricity Board, BSEB, West Bengal State Electricity Board, WBSEB), the CESC has a significant share in thermal power generation. These coal-based plants are mainly concentrated in West Bengal and Bihar, close to the major coal fields of the country.

In 2000, there were 25 thermal power plants with 44 major generating units in the Eastern region. Besides coal-based power stations, the Eastern region also has 15 hydroelectric power stations and four high speed diesel oil (HSDO)-based gas turbines.

The following table represents the current status of the installed capacity of conventional power stations of the Eastern region in 1999-2000.

Table 5. Installed Capacity in the Eastern Region, 1999-00

Type	Installed capacity (MW)	Capacity percentage
1.Coal Thermal	14211	84
2.Hydro	2567	15
3. Gas Turbine	195	1
Source: Eastern Regional Electricity Board (2000)		

The Eastern region electricity industry is highly dependent on thermal power plants. Capacity expansion in the Eastern region is continuing and a large expansion has been planned over the next decade covering the tenth and eleventh Five-Year Plan periods starting from 2003. Twenty-five units (including conventional and non conventional fuel based) with total capacity of 4,283 MW (25% of the total existing capacity) have begun operation since 1994. Of these, 81% are thermal with coal as the primary fuel source, 15% (about 650 MW) are hydro and the remainder (about 170 MW) are renewable sources such as solar and wind to meet the off-grid supply. These additions were financed by DVC, GRIDCO, WBSEB, CESC, NTPC, NHPC (National Hydro Power Corporation), and WBREDA (West Bengal Renewable Energy Development Agency). The future expansion plan of the next decade proposes to construct 26 power stations with a total capacity of 24,313 MW, details of which are given in Table 6.

Table 6. Future Capacity Addition Plans for the Eastern Region

Type	Capacity(MW)	Status	Ownership
Hydro	1067	expected by 2003-2004	Govt/PSU
Hydro	1220	expected by 10th plan	Govt/PSU
Hydro	4306	expected by 11th plan	Govt/PSU
Thermal	5450	expected by 10th plan	Govt/PSU
Thermal	2420	expected by 10th plan	Private
Thermal	7221	expected by 11th plan	Govt/PSU
Pump storage	900	expected by 10th plan	Govt/PSU

Source:EREB.

As in the other parts of the country, the Eastern region has a power deficit. Faster growth in power demand arising out of proposed industrial expansion and reduced use of petroleum products in rural areas contributes as well to this problem.

7. Baselines for Eastern Regional Grid in India

A key decision in determining baselines is to identify the plants to be included in the baseline. The potential CDM projects will be measured against the performance of these plants or units. Performance is measured in terms of carbon intensity (kgC/kWh). For any project to get credits through the CDM process, the "additionality" of the project must be determined. This necessitates knowledge of the baseline or "what would have happened anyway". Projects under the CDM get credit if they perform better than the baseline.

There are several issues which need to be resolved and which will have varying implications for the "additionality" and hence "carbon credit". Baseline may be constructed according to:

- Aggregate sectoral trend in past five-six years or decade
- Generation Fuel type: Coal based, Oil based, Hydro, Nuclear
- Ownership type, i.e., company based
- Project-specific performance

There are several advantages and disadvantages of each of these methods but if we take minimisation of transaction cost as the primary objective then a sector wide baseline that represents multiple projects may be the best alternative. The main focus of this work is to generate multi-project baselines for the Eastern region in India. Based on these multi-project baselines we estimate carbon credits that may be generated by several types of hypothetical CDM projects.

8. Recent Plant or Near Future

There are various alternatives for construction of multi-project baselines. One approach is to use data for recently constructed plants, assuming that these represent the best available technology. "Recent" may mean the past 3 to 5 years. An advantage of this approach is that the data for such plants is observable. A forward-looking baseline, which includes future plants, has the advantage that it can consider new, more efficient technologies. However, a forward-looking baseline needs to make additional assumptions about which plants would most likely be built in the future. Arguably it may be more "realistic" about what new technologies are likely to be used. The negotiating text defines a "reference scenario" as "a set of recent and comparable activities or facilities which are defined in a manner sufficient to demonstrate what would likely have occurred in the relevant sector in the absence of the proposed project activity" (UNFCCC 2000, § 60). The reference scenario can therefore be based on recently constructed plants or near future ones. The planned near future plants for the Eastern region (Table 6) will be using the same fuel source as plants constructed in the recent past except for the proposed pump storage facility.

9. Data and Methodology

The data essential for setting multiproject baseline are the fuel input (in GJ per year) and the electrical output (in TWh per year) of power plants. Combining this information with carbon content, we can calculate the carbon intensity. The carbon intensity is measured in mass of carbon per unit of energy produced, e.g. in units of kg CO_2/kWh. These data, if available at the lowest micro unit, yield the best result. For the Eastern region, we were able to collect the generation figures for each power plant unit . However, the fuel consumption data are based on average figures for the plant since unit-specific data were not available. Data have been collected from government publications at the regional offices of the Central Electricity Authority (CEA) and the West Bengal State Electricity Board. Plants have one or more units of differing vintages at the same site. Data are more readily available at the plant level, but analysis at this level may produce less stringent baselines if the plant includes many later vintage units, so we use the data collected from the monthly power generation and fuel consumption reports submitted by the individual units to the EREB. Coal factor and heat content data are India specific while carbon content data are the IPCC default values.

A second decision is to which set of plants to compare the potential CDM project. For example, does a new gas plant need to perform better than the average power station in the whole sector, the average fossil-fueled plant, or only better than other gas-fired plants? These comparisons can be applied to different sub-sets of the plants in the baseline. The project can be compared to other plants using the same fuel ("fuel-specific"), to all fossil fuel-fired plants ("all fossil"), or to the whole electricity generation ("sector-wide"). Obviously, the fuel-specific comparison is valid only if there is a plant or unit in the baseline using the same fuel as the project.

The third decision is whether to compare projects against average, better-than-average, or best plants. Once the carbon intensity of the plants in the reference scenario are known, we can construct increasingly stringent benchmarks – a "weighted average", "25th percentile", "10th percentile" or "best plant". One would expect the carbon intensity required by each of these benchmarks to be *lower* – in other words, the CDM project will have to show lower carbon intensity than a more stringent target. We report below the five scenarios that can be constructed as benchmarks for the Eastern regional power sector if power plants that have been built over last six years are used as the baseline.

10. Results

Table 7 shows the baseline intensities – both energy and carbon intensity – given the units included in the "recent past" baseline. No energy intensity is reported for the sector as a whole, since this concept has different meanings for fossil fuel plants and those using hydro and renewable energy sources. There is no "fuel" for hydro-power, so no fuel-specific intensities are reported. There are no plants, which use only one type of fuel. All thermal plants use coal and oil. Although coal-fired plants use coal as primary fuel, they do keep provision for use of oil as a supplementary fuel for two reasons: one for starting the system and second to supplement the primary fuel in case of supply shortage or technical fault and hence non-availability of the coal racks. Hence we cannot report any figures for coal-specific units. For hydro we assume that the carbon intensity is zero. Carbon intensity represents the baseline for CDM projects; energy intensity is reported for information only.

The benchmarks increase in stringency from left to right, as expected. The all-fossil energy and carbon intensity are identical whether one uses the "10th percentile" or "best plant". This is because several of the coal units included in the baseline have identical performance. The zero carbon intensity for the sector-wide category reflects the inclusion of hydro and solar energy-based power-generation, which is zero-emitting. The baseline generally gets more stringent as one moves from all-fossil to sector-wide comparisons since the sector includes hydro and solar. The "best plant" benchmark will therefore always be zero whenever electricity is supplied by such plants.

Table 7. Energy and Carbon Intensities for the Recent Past Baseline

			Weighted Average	Percentile 25%	Percentile 10%	Best Plant
All Fossil	Energy intensity	MJ/kWh	13.84	9.39	8.43	8.43
	Carbon intensity	Kg C/kWh	0.345	0.241	0.217	0.217
Sector wide	Carbon intensity	Kg C/kWh	0.341	0.228	0.192	0.000

Source: authors' calculation.

11. Potential CDM Projects

The choice of potential CDM projects to include in the analysis is based on hypothetical examples. Since the purpose of this analysis is to investigate the impact of different baselines. However, to make the analysis worthwhile, realistic hypothetical cases have been selected. For this analysis, we choose four projects, keeping in view the plans in next decade in the Eastern region and including diverse projects – some using fossil fuels, others using hydro and renewable resources, as well as on-grid and off-grid projects:

- The Balagarh (500 MW capacity) and Maithon (1000 MW capacity) thermal power projects are planned under private and public sectors respectively. They have been planned to use better quality coal and less oil input, and should operate more efficiently than existing plants.
- Tala and Teesta are the large hydro projects of 1020 MW and 1710 MW capacity respectively

- A total of six MW of generating capacity under the renewable energy development agency has been planned for decentralised off-grid supply of power. Off-grid Solar Home Systems have been used to electrify rural areas unlikely to receive grid electricity. It is more likely that kerosene will be displaced for lighting. In comparing this programme to the multi-project baseline, one implicitly assumes that it will replace electricity.

This set of CDM projects in no way claims to be comprehensive[6]. We chose a small sample of projects that in our opinion are likely to provide enough information if any ground work for CDM projects is started at the policy level. Table 8 lists the projected performance data used to compare these five CDM projects to various baselines.

Table 8. Key Characteristics of Potential CDM Projects

	Tala	Teesta ST III & IV	Maithon Right Bank	Balagarh	Renewable
Capacity [MW]	1020	1710	1000	500	6
Annual generation [TWh]	4.468	7.490	6.132	3.504	0.006
Annual fuel use [GJ]					
Coal			52,241,574	29,852,328	
Oil			1,370,489	783,137	
Carbon intensity [kg C / kWh]	0.000	0.000	0.220	0.220	0.000

Sources: Developed from the Proposed Generation Plans available from EREB and WBREDA.

12. Decrease in Carbon Intensity from CDM Projects under Recent Past Baseline

Table 9 compares the performance of projects against different baselines. It shows by how much the CDM project's intensity was lower than the baseline. A positive number indicates a lower carbon intensity than the baseline. The larger the number, the better the performance in terms of carbon intensity. Positive numbers show viable CDM projects.

Results suggest that:

- Carbon savings generated from fossil fuel based CDM projects, Maithon and Balagar, decline as one moves from the "all fossil" to the "sector-wide" baseline, since the latter includes hydro and renewables. Using the the fossil-fuel based plants are considered we find that the two thermal projects perform worse than the "best plant" and "10 percentile" plants. With a sector-wide comparison, thermal projects would be less likely to attract CDM investment with stringent baselines.
- Renewables and hydro projects do well under all scenarios. To determine eligibility, renewables in India should be compared to the sector-wide values, since they might substitute a wide range of electricity sources, not only coal.
- In a coal-dominated energy economy, the benefit of moving to hydro and renewables are significant.

[6] Projects that are *not* included in the analysis are the nuclear, gas, imported coal due to the uncertainty whether nuclear technologies can be accepted as CDM projects, and how far the other types will be installed in the region.

- The additional credits from a less stringent baseline can be quite substantial, as shown in the annual emissions reductions in kilotonne of carbon in Table 10. The results reflect the different sizes of projects, as well as their carbon intensities.
- The relatively small absolute carbon reductions for off-grid solar projects are primarily due to the small size of the project (6 MW).
- If better-than-average benchmarks (e.g., "10th percentile") are applied, the fossil-fuel CDM projects result in relatively small or no carbon reduction for their size.

Table 9. Reduction in Carbon Intensity Baseline [kg C/kWh] from CDM Projects Relative to Recent Past

	Baseline standard	Tala	Teesta ST III & IV	Maithon Right Bank	Balagarh	Renewable
All fossil	Weighted average	0.345	0.345	0.126	0.126	0.345
	25th percentile	0.241	0.241	0.021	0.021	0.241
	10th percentile	0.217	0.217	-0.003	-0.003	0.217
	Best plant	0.217	0.217	-0.003	-0.003	0.217
Sector wide	Weighted average	0.341	0.341	0.122	0.122	0.341
	25th percentile	0.228	0.228	0.008	0.008	0.228
	10th percentile	0.192	0.192	-0.027	-0.027	0.192
	Best plant	0.000	0.000	-0.220	-0.220	0.000

Source: author's estimates.

Table 10. Carbon Reductions by Project Based on Recent Past Baseline [Thous. t C/yr]

	Baseline standard	Tala	Teesta	Maithon	Balagarh	Solar
All fossil	Weighted average	1,543	2,587	770	440	2
	25th percentile	1,076	1,803	129	73	1
	10th percentile	967	1,622	none	none	1
	Best plant	967	1,622	none	none	1
Sector wide	Weighted average	1,526	2,558	746	426	2
	25th percentile	1,016	1,704	47	27	1
	10th percentile	859	1,441	none	none	1
	Best plant	none	none	none	none	none

Source: authors' estimates.

13. Concluding Remarks

This analysis provides some useful guidelines for future choice of power projects in the Eastern region if carbon intensity reduction is the objective. Given that demand for power will be on the rise, and taking into account unmet demand, it is very likely that low-gestation period coal based thermal plants will be on the priority list. In such a scenario, the increasing damage to the environment can be mitigated through increased efficiency and use of low carbon fuels. An extremely pertinent issue is how do we look at the CDM projects: as a source of investment in more expensive projects or as means to address both investment source and environmental objective? Given the recent past experience, any efficient thermal plant can earn credit compared to the baseline if less than 'best plant' scenario is considered. If the current rate of subsidy given for establishment of renewable power plants is considered then the argument in favor of commercial adoption of these investments may be questioned. These issues become more relevant once the institutional changes in terms of liberalisation and invitation for private investment in power sector are considered. Given that the public sector would still continue to hold a very important position in the power sector, investment in new power projects may be monitored through these sector-wide baseline estimates.

Another primary question in terms of the CDM is can we consider the thermal, hydro and renewables as "additional" in the Eastern region of India? Past and near future plans may confirm that they are happening anyway in this region for commercial reasons. In that sense maybe gas based power plants and nuclear are the only candidates for the CDM. It is hard to solve this issue given the scope of this study. The present study does not address the full question of additionality as it is focused at estimation of baseline only. More accurate baselines could be established in future studies if the following could be accomplished:

- Improving data quality, e.g., actual coal consumption per power unit in the power stations rather than average consumption reported.
- Using the plant specific calorific value and carbon content of the coal used.
- Estimation of other power plant types from other regional grids, e.g., gas-based and nuclear plants to establish sector-wide as well as country-wide baselines.
- Making the baselines adjustable.
- Calculating baseline for privately- and publicly-owned plants separately since the latter sometimes do not follow commercial principles.

Acknowledgments

This paper was written as part of a project led by Lawrence Berkeley National Laboratory to investigate the use of multi-project baselines for projects in the electric power and industrial sectors. An earlier version of this paper was presented at the Conference of Parties of the UNFCCC at The Hague, Netherlands in November 2000.

References

Central Statistical Organization, 2000. Energy Statistics, 1998, Department of Statistics, Calcutta, India.

Dasgupta, M and Joyashree Roy, 2000. "Manufacturing Energy Use in India: A Decomposition Analysis", *Asian Journal of Energy and Environment.*.

Eastern Regional Electricity Board (various issues) Annual Report, Calcutta, India.

Eastern Regional Electricity Board, Unpublished documents.

Goldemberg, Jose (ed.), 1998. *Issues and Options: The Clean Development Mechanism*, United Nations Development Programme, New York.

Grubb, Michael, 1999. *The Kyoto Protocol: A guide and Assessment*, Royal Institute of International Affairs, London.

Howells, Mark, 1999. "Baseline and Greenhouse Gas Mitigation Options for Bulk Energy Supply", *South African Country Study_on Climate Change*, draft, Energy Research Institute, University of Cape Town.

International Energy Agency (IEA), 1999, Key World Energy Statistics, 1999.

International Energy Agency, 1998. CO_2 emissions from fuel combustion, 1971 – 1996, OECD, Paris.

IPCC (Intergovernmental Panel on Climate Change), 1995. *Greenhouse Gas Inventory Workbook*, vol.2, UNEP, OECD, IEA and IPCC, London.

Karottki, Rene, and Doug Banks, 2000. "Power and Profit? Electrifying Rural South Africa", *Renewable Energy World* Jan 2000, pp. 51-59.

Lazarus, Michael, Sivan Kartha, Michael Ruth, Steve Bernow and Carolyn Dunmire, 1999. *Evaluation of Benchmarking as an Approach for Establishing Clean Development Mechanism Baselines*, Tellus Institute, Boston.

Meyers, Steve, 2000. *Determining Baselines and Additionality for the Clean Development Mechanism: Are Simplified Methods Viable?* Forthcoming, Lawrence Berkeley National Laboratory, Berkeley.

Planning Commission (1997) Approach to the Ninth Five Year Plan. Government of India, New Delhi.

United Nations Framework Convention on Climate Change (UNFCCC), 2000. Mechanisms Pursuant To Articles 6, 12 And 17 of the Kyoto Protocol: Text by the chairmen: Addendum: Article 12 of the Kyoto Protocol UNFCCC document FCCC/SB/2000/Add.2.

UNFCCC, 1992. United Nations Framework Convention on Climate Change.

UNFCCC, 1997. Kyoto Protocol to the United Nations Framework Convention on Climate Change, document FCCC/CP/1997/7/Add.1

West Bengal Renewable Energy Agency (2000) Personal communication and unpublished reports.

LBNL-48242D

Potential Multi-Project Baselines
in the Power Sector in South Africa

Harald Winkler, Randall Spalding-Fecher, Yaw Afrane-Okese, Ogunlade Davidson
Energy & Development Research Center
University of Cape Town
Cape Town, South Africa

Jayant Sathaye and Lynn Price, Editors
International Energy Studies Group, Energy Analysis Department
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory
1 Cyclotron Road, MS 90-4000
Berkeley, CA 94720 USA

2001

LBNL-48242D

Potential Multi-Project Baselines In The Power Sector In South Africa

Table of Contents

Potential Multi-Project Baselines
in the Power Sector in South Africa

Harald Winkler, Randall Spalding-Fecher, Yaw Afrane-Okese, Ogunlade Davidson
Energy & Development Research Center
University of Cape Town
Cape Town, South Africa

Abstract

The energy sector in South Africa is one of the major drivers of GHG emissions. While South Africa currently emits only 1.6% of global industrial carbon dioxide emissions, per capita emissions, at 8.5 tons per capita, are close to some OECD countries and far higher than most developing countries. In fact, South Africa alone contributes 49% of Africa's CO_2 emissions, while emissions per kWh from electricity generation, for example, are considerably higher than for many industrialised economics. This is related to the energy intensive structure of the South African economy, as well as the high dependence on coal as a primary energy source. For these reasons, energy efficiency projects for the electric sector need to be encouraged. Development of multi-project baselines to evaluate proposed projects may simplify the process of project approval and calculation of credits for chosen projects. This paper evaluates the use of such multi-project baselines for the South African power generation sector. The analysis found that a backward-looking baseline using data from recently-constructed plants is not appropriate in South Africa because of the small number of recently-constructed plants and changes in new, marginal plants. Instead, using a "near-future" baseline that includes two new coal-based plants, a new natural gas plant, the recommissioning of two moth-balled coal units, and imported hydro. Five potential energy efficiency projects were evaluated using this baseline. We found that a baseline looking at near future plants is more effective in ensuring environmental integrity than a baseline using recently-constructed plants. We conclude that one option is to use a sector-wide, 25th percentile baseline for all projects in the electricity generation sector while a second option is to choose different baselines for projects with different attributes.

1. Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) aims to reduce emissions of greenhouse gases (GHGs) in order to 'prevent dangerous anthropogenic interference with the climate system' and promote sustainable development (UNFCCC 1992). The Kyoto Protocol, which was adopted in 1997, aims to provide means to achieve this objective.

The Clean Development Mechanism (CDM)[1] is one of three 'flexibility mechanisms' in the Protocol, the other two being Joint Implementation (JI) and Emissions Trading (ET). These mechanisms allow flexibility for Annex I Parties[2] to achieve reductions by extra-territorial as well as domestic activities. The underlying concept is that trade and transfer of credits will allow emissions reductions at least cost. Since the atmosphere is a global, well-mixed system, it does not matter where emissions are reduced.

The CDM allows Annex I Parties to meet part of their emissions reductions targets by investing in developing countries. The host developing country benefits from the project. CDM projects must also meet the sustainable development objectives of the developing country. Further criteria are that Parties must participate voluntarily, that emissions reductions are 'real, measurable and long-term', and that they are additional to those that would have occurred anyway. The last requirement makes it essential to define an accurate baseline.

1.1 Baselines and additionality

Reductions of GHG emissions must be additional to business-as-usual. If a project would have happened anyway, it should not be a CDM project and receive investment through that mechanism. Once a project has qualified for the CDM and been implemented, the certified emissions reductions need to be calculated. To do so, the different between the projected baseline and the project performance needs to be calculated.

Like any projection, baselines depend on assumptions about the future. Key assumptions include the level of economic growth, energy supply and demand, and the emissions assumed as a starting point. Baselines are counterfactual, in the sense that, due to climate change policy, the baseline will never occur.

The possibility that the determination of additionality may be separated from the calculation of credits has been discussed in the climate negotiations. Additionality may be tested by use of various 'additionality screens', including environmental, financial, investment and technological additionality (UNFCCC 2000). The methodology for calculating baselines to determine credits may be separate. The purpose of this paper is to consider the calculation of baselines, rather than dealing explicitly with additionality.

1.2 Minimising transaction costs while ensuring environmental integrity

The aim of multi-project (or standardised) baselines must be to seek a balance between ensuring environmental integrity and minimising transaction costs. Setting project-by-project baselines would increase the transaction costs of CDM projects and thus reducing the number of projects

---

1 See Michael Grubb (1999) for a more detailed description of the CDM and its origin in the negotiations.

2 Annex I Parties are industrialised countries and countries with 'economies in transition', which are listed in Annex I of the Convention. Developing countries are referred to as non-Annex I Parties.

that attract investment. The experience of the AIJ[3] pilot phase was that baselines are time-consuming and highly subjective. Hence there have been suggestions to standardise baselines across many projects, to set them for particular sectors, or given technologies. Multi-project baselines based on emissions intensity are known as benchmarks.[4] A concern about multi-project baselines is that they might undermine the environmental integrity, in that emissions reductions might be credited that are not ‘real’. This paper explores alternative options for multi-project baselines.[5]

Establishing a baseline for a particular activity, sector and/or region potentially simplifies the calculation of emissions reductions. Baselines need to be simple enough to be practical in developing countries. Various proposals for baselines are summarised in the Chairman’s Draft Text on Mechanisms (26 October 2000) for the climate change negotiations. In bracketed text, it proposes that baselines for a CDM project should consider the lowest of:

a) ‘Existing actual emissions prior to the project;
b) The most reasonable economic technology for the activity;
c) Better-than-average current industry practice in the host country or an appropriate region; and
d) The (average) (top X per cent) for such an existing source in Parties included in Annex (I) (II).’

(UNFCCC 2000, FCCC/SB/2000/Add.2: § 70)

While project-specific baselines may be costly, less stringent baselines pose a potential threat to the environmental integrity of the Protocol. If a multi-project baseline allows projects that would have occurred under business as usual, then free riders can claim credits for something that would have been created anyway. This threatens environmental integrity in that the project does not really add to global emissions reductions. Under the CDM, both investor and host countries would have an incentive to inflate baseline emissions.

This paper considers a number of approaches to multi-project baselines for the electricity generation sector, and the implications for a set of potential CDM projects in South Africa.

2. Background to the SA energy sector

Primary energy consumption in South Africa is dominated by coal (70%). Coal dominates electricity generation (91%), and South Africa has amongst the cheapest coal and electricity in the world. Of primary energy, 20% is attributable to petroleum products [DME, 2000 #242].[6] The energy sector also includes a synthetic fuel industry that produces oil from coal. Nuclear, gas, renewables and biomass make up the balance of the energy supply.

South Africa’s GDP ranks 26th in the world, but primary energy consumption is 16th (DME 1996) and energy intensity is 77% above global average. This is largely a result of the presence of large-

3 Activities Implemented Jointly. The AIJ pilot phase was initiated at the first Conference of the Parties to test the impact of implementing emissions reductions projects in some countries (developing countries or economies in transition) and funded by others without generating credits.

4 See M. Lazarus *et al* (1999) for an evaluation of different approaches to benchmarking, and case studies of Argentina, China, South Africa, Thailand and the United States.

5 This paper does not analyse the difference between multi-project baselines and a project-specific approach, a topic that warrants further attention.

6 This is net of exports – South Africa exports refined products to other SADC countries

scale energy-intensive primary minerals beneficiation industries, the reliance on coal for electricity generation, the production of a significant proportion of liquid fuels from coal via the synthetic fuel process, and low efficiency in many industrial and commercial processes.

Energy policy in post-apartheid South Africa locates energy in the context of sustainable development. It aims to:

- improve *social equity* by specifically addressing the energy requirements of the poor;
- enhance the *efficiency and competitiveness* of the South African economy by providing low-cost and high quality energy inputs to industrial, mining and other sectors within restructured and appropriately governed energy markets ; and
- work towards *environmental sustainability* by addressing both short-term environmental problems, and planning for a long-term transition towards sources of energy with minimum negative environmental impacts.

The energy White Paper, released in late 1998, presents a comprehensive set of energy sector policies. Key policy elements from the White Paper and priorities outlined by the Minister of Minerals and Energy are reflected below:

- Electricity policies include a continued massive electrification programme; restructuring of the electricity distribution and supply industries; integrated resource planning to meet demand growth; and reform of the pricing system to more accurately reflect costs. While renewables are not explicitly supported, government recognises the role they have to play in rural electrification and is working on an implementation plan for renewables.
- In the oil and gas industry, government plans to progressively re-regulate the industry and to promote the introduction of natural gas from neighbouring countries.
- Coal policies focus mainly on containing the environmental consequences of coal production, and the utilisation of coal-bed methane.
- Integrating concerns about black economic empowerment, HIV/AIDS, empowerment of women, and health and safety into strategies in the energy sector.

2.1 Overview of the electricity generation sector

The electricity supply industry in South Africa is almost entirely in the hands of the public sector – either through Eskom or municipal distributors. Figure 1 illustrates the current structure of the electricity supply industry. Generation and transmission are dominated by Eskom. There are a few self-producers, some of which sell to neighbouring communities. Eskom owns 92% of all generation capacity in South Africa, municipalities own 6% and private generators only 2%.

The total quantity of electricity generated in South Africa in 1999 was 190 TWh (NER 1999). Eskom accounted for 96% of this total. Figure 2 presents the electricity flows in the South African industry for 1996, the latest year for which such detailed breakdowns are available.

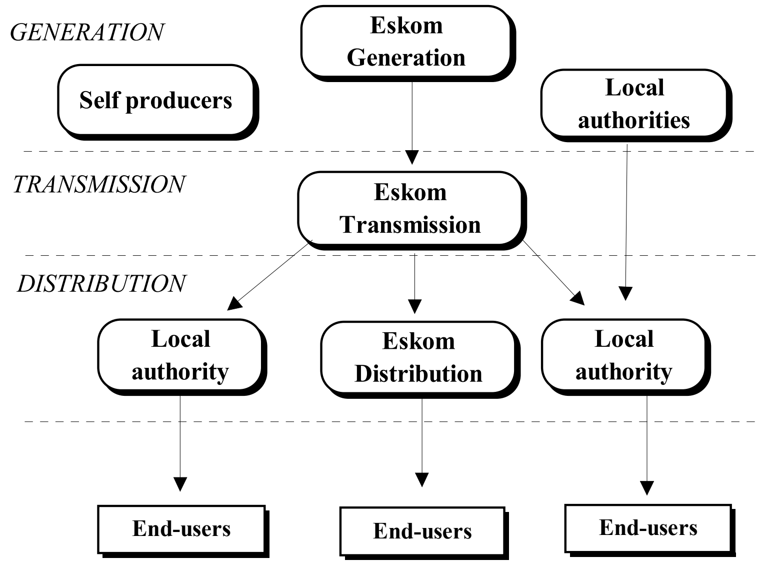

Figure 1. Structure of the South African electricity supply industry

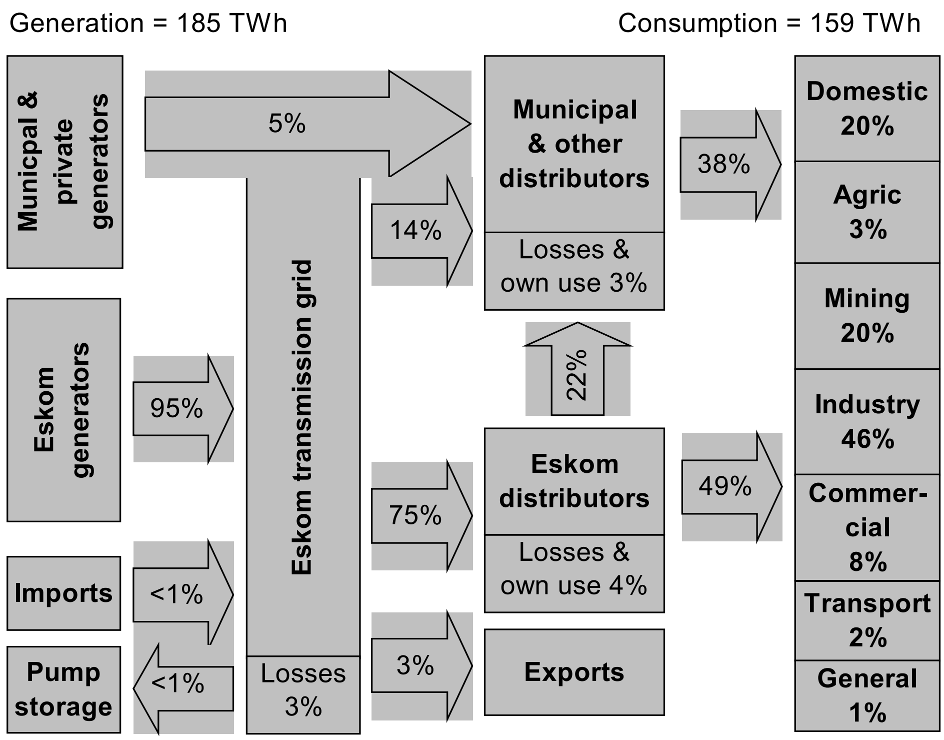

Figure 2. Energy flows in the electricity supply industry in 1996

South Africa's electricity generating technology is based largely on coal-fired power stations, mostly owned and operated by Eskom and largely concentrated near and to the East of Johannesburg – close to the main coal resources as well as the country's major demand centre (see Figure 3).

As at the end of 1999, there were 49 power stations in the country, of which 20 were coal-fired accounting for 90% of the total capacity of 42 994 MW (excluding capacity in reserve and under construction). Many power stations were constructed during the 1960s and 1970s, before growth in demand slowed. Three of Eskom's older coal stations are currently in reserve ('mothballed') due to the existence of excess capacity and would account for an additional 3 556 MW. The only non-coal stations of significance are the Koeberg station (4% of operational[7] capacity) and three pump storage facilities (4% of operational capacity) (NER 1999; Eskom 1999).

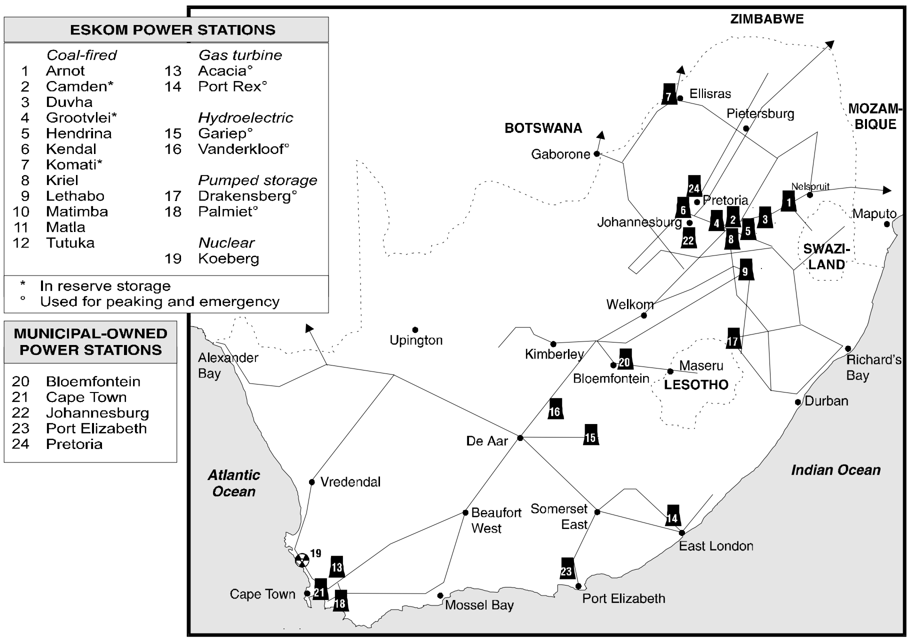

Figure 3. Geographical distribution of electricity generating stations in South Africa

Table 1 presents the breakdown of capacity and electricity production by fuel source. Coal generation accounts for 91% of all electricity produced and nuclear generation a further 7%.

The average age of Eskom's operational power stations is 14 years (weighted by capacity) – this figure is heavily influenced by several large stations constructed in the 1980s. Eskom's moth-balled stations are 30 years old on average and would typically have lower than average thermal efficiencies.

South Africa is known for being one of the world's low-cost producers of electricity. At the beginning of 1997, Eskom, the electric utility had the lowest industrial electricity tariffs in the world: at 2c/kWh, South Africa was followed closely by only New Zealand at 2,5 c/kWh (SANEA 1998).

---

[7] 'Operational' capacity excludes all moth-balled stations and units under construction.

Eskom's coal-fired power stations generally exhibit high thermal efficiencies for conventional pulverised fuel technology. Average efficiencies have consistently been over 34% for the past six years, despite the use of low quality (high ash) coal and the use of dry-cooled technology, which is generally slightly less efficient than wet-cooled stations. The weighted average heat content for existing coal-fired power stations is low at 21.3 GJ/t (coal) compared to the IPCC default value of 29.3; carbon content is relatively high at 28.2 tC/TJ compared to the IPCC factor of 25.8 (IPCC 1995).

The high dependence on coal means that South Africa's electricity industry has relatively high greenhouse gas (GHG) emissions of 178 Mt of CO_2 equivalent in 1998 (see Table 2). This is mainly from coal combustion, but includes some methane emissions from coal mines. Overall, South Africa produces 1.04 kg of GHG per kWh produced.

Table 1. Capacity and electricity production by fuel type

	Operational capacity (1999)[a] [MW]		**Gross electricity production (1999) [GWh]**		**Net electricity sent out (1997)[b] [GWh]**	
Coal	38287	90.0%	173339	91.2%	173339	93.0%
Nuclear	1840	4.3%	12837	6.8%	12837	6.9%
Pumped storage[c]	1580	3.7%	2837	1.5%	-918	-0.5%
Hydro	668	1.8%	927	0.5%	927	0.5%
Gas	662	1.5%	5	0.0%	3.8	0.0%
Bagasse	105	0.2%	196	0.1%	196	0.1%
Total	43142	100%	190141	100%	186385	100%

Notes:

Excluding capacity in reserve and under construction.

Net electricity sent out excludes own use by the generator, but includes captive production used on site by producers.

While pumped storage contributes to gross energy production, it is, in fact, a net user of electricity.

Source: NER (1999)

2.2 Energy and GHG emissions

The energy sector in South Africa is one of the major drivers of GHG emissions. The most recent inventory of these shows that South Africa contributed 1.02% to the human-induced additional radiative forcing of the atmosphere due to CO_2, CH_4, and N_2O in 1990. Of the 373 022 Gg of CO_2 equivalent emissions in that year (or 101.8 MtC), the energy sector accounts for 89%. This includes a number of critical energy-related activities such as: generation of electricity (48%), energy used in manufacturing (7%), energy used in transport (9.3%), heat production (8.8%), petroleum industry (9.9%), other energy related activities (7%) (Van der Merwe & Scholes 1998).

While South Africa currently emits only 1.6% of global industrial carbon dioxide emissions, per capita emissions, at 8.5 tons per capita, are close to some OECD countries and far higher than most developing countries (IEA 2000). In fact, South Africa alone contributes 49% of Africa's CO_2 emissions (ibid.), while emissions per kWh from electricity generation, for example, are considerably higher than for many industrialised economics (NRDC/PSEG 1998). This is related to the energy intensive structure of the South African economy, as well as the high dependence on coal as a primary energy source.

3. Baselines for SA electricity generation

A key decision in determining baselines is to identify the plants to be included in the baseline. It is the performance of these plants or units that the potential CDM projects will be measured against. Performance is measured in terms of carbon intensity (kg C / kWh).

Table 2. Estimated emission of GHGs due to electricity generation (1998)

	Electricity generated (GWh)	Primary energy used (GWh)	GHG emission (Mt CO_2 equiv)	Emission factor (kg of CO_2/ kWh generated)
Coal	170 750	508 988	178	1.04
Nuclear	13 601	n/a	0	0
Pumped storage	2 626	n/a	0	0
Hydro	1 852	n/a	0	0
Gas[8]	23	64	0.2	2.79
Bagasse	86	n/a	n/a	n/a
Total (all fuels)	188 938	509 052	178	0.95

Source: Based on Eskom (1998b), Eskom (1999), Praetorius & Spalding-Fecher (1998)

3.1 Recent or near future plants

One approach is to use data for recently constructed plants, assuming that these represent the best available technology. 'Recent' might mean different lengths of time, perhaps three to five years. An advantage of this approach is that the data for such plants is observable. This does not mean that there is no uncertainty about observed data. However, a forward-looking baseline that includes future plants needs to make additional assumptions about which plants would most likely be built. A forward-looking baseline has the advantage that it can consider new, more efficient technologies. Arguably it is more 'realistic' about what new technologies are likely to be used. The negotiating text defines a 'reference scenario' as 'a set of recent and comparable activities or facilities that are defined in a manner sufficient to demonstrate what would likely have occurred in the relevant sector in the absence of the proposed project activity' (UNFCCC 2000, § 60). The reference scenario can therefore be based on recent plants or near future.

In South Africa, the backward-looking approach does not work for practical reasons. Only one power station, Majuba, has been constructed in the last seven years.[9] Here, four units have been constructed between 1996 and 1999, and two more are being constructed during 2000 and 2001. If one uses the 'recent plant' approach, one therefore compares the CDM projects to the performance of a single power station. The slower growth in demand in South Africa in recent years creates some inertia against changes in the capacity mix (Lazarus 1999). Opportunities to change the capacity mix towards low-carbon technologies are constrained by the existence of excess capacity and moth-balled coal stations. These arguments are specific to the power sector in South Africa, and do not imply that other developing countries might not choose recent plant baselines.

8 While CCGT stations tend to have thermal efficiencies almost double that of coal plants (and so emit less CO_2), gas stations in South Africa are single-cycle and used for peaking. Thus their efficiency is low resulting is comparatively high CO_2 emissions per kWh generated.

9 The last previous plant was Kendal, whose units were commissioned from 1988-1993 (Eskom 1996).

A more general point is that forward looking baselines are open to 'gaming'. Countries have an incentive to choose a reference scenario with high carbon intensity, so that CDM projects will be able to sell more credits. Gaming is also a problem for project-specific baselines. It can be avoided to some extent by including factors that are difficult to change – for example, requiring the projection to be based on published government or utility plans. Setting regional baselines also makes gaming more difficult, as would a system of international review (Meyers 2000). To the extent that gaming cannot be avoided, there is a trade-off between this risk and the risk of free riders against a backward-looking baseline that does not promote the best available technology.

In this analysis, we have therefore chosen a baseline that includes 'near future' plants. These include the two new units of Majuba, the recommissioning of two units in moth-balled power stations, the importation of hydro, and new gas plant. Given the directions set by Eskom's Integrated Electricity Plan 6, one could reasonably expect these units to come on line between 2000 and 2005.

Table 3. Key characteristics of a 'near future' baseline

	Majuba Unit 5	**Majuba Unit 6**	**Mothballed coal 1**	**Mothballed coal 2**	**New gas**	**Imported hydro**
Capacity (MW)	713	713	570	870	736	400
Efficiency assumed	34%	34%	30%	30%	55%	
Annual generation (TWh)	3.78	3.78	3.02	4.61	4.13	1.84
Annual fuel use (GJ)						None
Coal	39,511,269	39,511,269	6,252,666	55,333,017		
Natural Gas					27,057,200	
Carbon intensity (kg C / kWh)	0.295	0.295	0.338	0.338	0.100	0.000

Sources: Developed from data in NER (1999), Eskom (1996; 1998a; 1999)

Some key results are compared using the 'recent plant' baseline, that is, considering the Majuba power station only.

3.1 Basis of comparison

Three key decisions are required to calculate the baseline:[10]

- The first decision is which set of plants to include in the reference scenario. For each plant, the essential data is the fuel input (in GJ per year) and the electrical output (in TWh per year). Combining this information with the calorific value of the fuel and its carbon content, we can calculate the carbon intensity. The carbon intensity is measured in mass of carbon per unit of energy produced, e.g. in units of kg CO2/kWh.
- The second issue is to which set of plants the potential CDM project should be compared. For example, does a new gas plant need to perform better than the average power station in the whole sector, the average fossil-fueled plant, or better than other gas-fired plants only? These comparisons can be applied to different sub-sets of the plants in the baseline. The project can be compared to other plants using the same fuel ('fuel-specific'), to all fossil fuel-fired plants

[10] These three decisions are analysed here. Lazarus *et al* (1999) note two further methodological issues – the degree of aggregation, and whether a static of dynamic baseline is used.

(‘all fossil’), or to the whole electricity generation (‘sector-wide’). Obviously, the fuel-specific comparison only works if there is a plant or unit in the baseline using the same fuel as the project.

- The third decision is whether to compare projects against average, better-than-average or best plants. Once the carbon intensity of the plants in the reference scenario are known, we can construct increasingly stringent benchmarks – a weighted average, 25th percentile, 10th percentile or the best plant. One would expect the carbon intensity required by each of these benchmarks to be lower – in other words, the CDM project will have to show lower carbon intensity than a harder target.

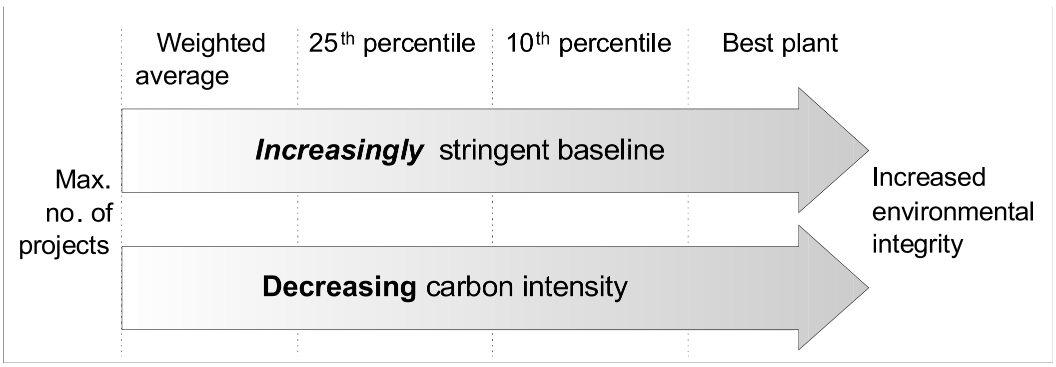

Figure 4. Relative stringency of different benchmarks

Table 4 shows the baseline intensities – both energy and carbon intensity – given the units included in the ‘near future’ baseline. No energy intensity is reported for the sector, since this concept has different meanings for fossil fuel plants and those using renewable energy sources. For gas, only the best plant shows a value, since percentiles or a weighted average cannot be calculated from a single plant (at least four are needed). There is no ‘fuel’ for hydro-power, so no fuel-specific intensities are reported. For the purposes of this analysis, we assume that the carbon intensity is zero, although this may well not be the case (WCD 2000). Carbon intensity represent the baseline for CDM projects; energy intensity is reported for information only.

Table 4. Energy and carbon intensities for the near future baseline

				Weighted average	**Percentile 25%**	**Percentile 10%**	**Best plant**
Fuel specific	Energy intensity	MJ/kWh	Coal	11.23	10.46	10.46	10.46
			Gas	6.55*	6.55*	6.55*	6.55
	Carbon intensity	Kg C/kWh	Coal	0.316	0.295	0.295	0.295
			Gas	0.100*	0.100*	0.100*	0.100
All fossil	Energy intensity	MJ/kWh		10.23	7.11	6.55	6.55
	Carbon intensity	Kg C/kWh		0.270	0.128	0.100	0.100
Sector wide	Carbon intensity	Kg C/kWh		0.247	0.065	0.013	0.000

Note: * Based on one plant only – see text.

The benchmarks get more stringent from left to right, as expected. However, the coal-specific carbon intensity is identical whether one uses the 25th percentile, 10th percentile or best plant. This is because several of the coal units included in the baseline have identical performance. Natural gas has much lower carbon intensity than coal – and this constitutes the best plant and 10th percentile for the 'all fossil' comparison. The zero carbon intensity sector-wide reflects the inclusion of imported hydro and the assumption that it is zero-emitting.

The baseline generally gets more stringent as one moves from fuel-specific to 'all fossil' and 'sector-wide' comparisons, as 'all fossil' adds in natural gas, and the sector adds the imported hydro, bringing down the weighted average carbon intensity.

Gas does not follow this trend, with the fuel-specific carbon intensity being lower than the all-fossil or sector-wide intensity, which include more carbon-intensive coal. The weighted average and percentiles for gas are based on one plant only. While it may be more mathematically correct to base such measures on more than the one gas plant included here, the value of the single plant is included across all, as that is what one would compare the project against. Figure 5 illustrates the near future baseline graphically, showing each plant's carbon intensity against its share of generation.

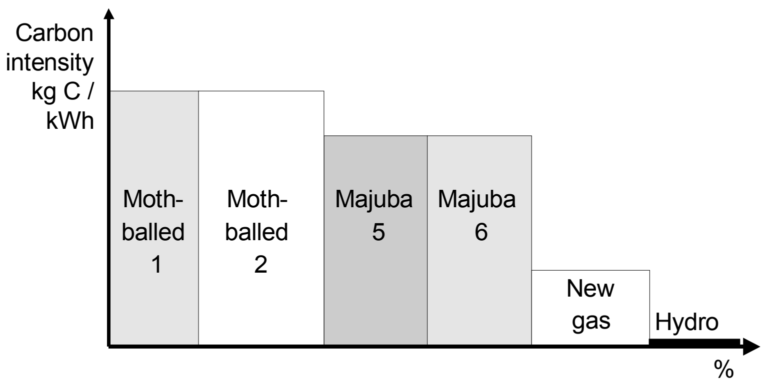

Figure 5. Near future reference scenario carbon intensity (kg CO_2/kWh) against the share of generation (TWh)

4. Potential CDM projects – supply options and demand interventions

A critical methodological choice is which potential CDM projects to include in the analysis. The purpose of this analysis is not to compare different CDM projects, but rather to investigate the impact of different baselines on hypothetical projects in South Africa. To make the analysis worthwhile, the data should be as close to likely reality as possible. For this analysis, we chose diverse projects – some using fossil fuels, others using renewable energy sources, as well as demand-side intervention and an off-grid project. Including both supply and demand-side options ensures that these interventions are treated equally.[11] These projects include the following:

[11] Evaluating demand-side CDM projects requires information about demand, which tends to have greater uncertainty than corresponding figures for supply side options (output and fuel use). So while the multi-project baseline makes the benchmark equal for all, the other half of the comparison is still uncertain. Rather than being an obstacle, however, this can be seen as further motivation to accept the additionality of energy efficiency projects.

- The Cape Metropolitan Local Authorities are investigating the feasibility of importing gas from the Kudu gas fields for three units of 368 MW each (Roggen 2000). New gas-fired power plants are substantially less carbon-intensive than coal-fired plants. Further possibilities being explored are using natural gas from fields off Mozambique and piping gas to Johannesburg.
- The Darling wind farm is aiming to install 5 MW for production of electricity for the grid. This independent power producer is the renewable energy project in South Africa which has progressed the furthest towards implementation (Asamoah 2000).
- As part of the South African Country Study on Climate Change, the possibility of more efficient, super-critical coal plants was investigated (Howells 1999). The more efficient use of coal in these plants could reduce greenhouse gas emissions.
- Eskom's Efficient Lighting Initiative aims to install 18 million compact fluorescent lights (CFLs) to reduce energy demand in the residential sector (Eskom 2000). Rather than increasing supply, this project aims to reduce demand for electricity, and thus avoid emissions. By including an energy efficiency options, it is possible to measure demand- as well as supply-side options against one multi-project baseline.
- Off-grid solar home systems have been used to electrify rural areas unlikely to receive grid electricity. The aim of the programme is to extend this from initial projects to a target market of 350 000 households (Qase 2000). In comparing this programme to the multi-project baseline, one implicitly assumes that it will displace electricity. It is more likely that paraffin will be displaced for lighting. This trade-off is necessary if one wants to benefit from the simplicity of applying a single baseline to many projects.

This set of CDM projects in no way claims to be comprehensive.[12] We chose a small sample of projects that, in our opinion, are likely early-start CDM projects, are the subject of major pending decisions, and /or use commercially available technologies. On the basis of the data in Table 5, these five CDM projects were compared to various baselines.

5. Comparing potential projects to baselines

Having identified a 'near future' reference scenario and potential CDM projects, the performance of each project can now be compared to various baselines and baselines. Table 6 shows how potential CDM projects perform in terms of carbon intensity. Energy intensity is also reported as background information.

5.1 Decrease in carbon intensity from CDM projects under near future baseline

Table 7 compares the performance of projects against different baselines. It shows by how much the CDM project's intensity *beat* the baseline. A positive number indicates a lower carbon intensity than the baseline; the bigger the number, the better the performance in terms of carbon intensity. Only with positive numbers is the project viable a CDM project.

[12] Projects that were *not* included in the analysis were the nuclear PBMRs, solar thermal technologies and IGCC new coal. Pebble Bed Modular Reactors are being investigated by Eskom, who are currently conducting an EIA for two pilot plants (110 MW each) at Koeberg. They were not included due the uncertainty whether nuclear technologies can be accepted as CDM projects. Solar thermal technologies for electricity generation are at an early stage of investigation in South Africa. The SA Bulk Renewable Generation (SABRE-Gen) project is conducting feasibility studies and demonstration facilities, but is not as close to implementation as wind. Integrated Gasification Combined Cycle (IGCC) new coal plants may achieve up to 55% efficiency, but are not expected to be implemented before 2025 (Howells 1999).

Table 5. Key characteristics of potential CDM projects
Sources: Developed from data in Roggen (2000),Karottki and Banks (2000); Howells (1999), Eskom (2000), Qase (2000)

	New gas: Cape Power Project	**Wind energy: Darling**	**New coal: supercritical steam**	**Efficient Lighting Initiative**	**Off-grid solar home systems**
Capacity (MW)	368	5	1 974	1 080 *	17.5
Efficiency assumed	55%	N/a	47%	N/a	N/a
Annual generation (TWh)	2.07	0.00876	10.46	4.00 *	0.02555
Annual fuel use (GJ)		None		None	None
Coal			80 137 473		
Natural Gas	13 528 600				
Carbon intensity (kg C / kWh)	0.100	0.000	0.216	0.000	0.000

*Avoided capacity and generation.

These results suggest that:

- Fossil fuel CDM projects struggle to beat the baseline if anything other than fossil fuels is included. One can see this trend for new gas and new coal, as one moves from the 'all fossil' to the 'sector-wide' comparison, with the latter including hydro. New coal, for example, beats the benchmark for 25th percentile under 'all fossil', but exceeds it in for with a sector-wide comparison. In short, with a sector-wide comparison, new coal and new gas projects would be less likely to attract CDM investment.
- Renewables do well under most comparisons, except the best plant sector-wide,[13] which compares them to zero-emitting imported hydro. To determine eligibility, renewables in South Africa probably should be compared to the sector, since they might substitute a wide range of electricity sources, not only coal.
- Gas looks best if you compare it to fossil fuels only, since in South Africa, that means mainly coal. The fuel-specific comparison for gas shows zero (equal performance), since units of new gas were included in the baseline, and another, identical unit included as a CDM project. The implication of this choice is that new gas projects would have to do better than ones included in the 'near future' baseline, in order to qualify as CDM projects and gain CERs. Thus assumptions about the type of gas plant that would have been built anyway are critical.
- In a coal-dominated energy economy, the benefit of moving to gas-fired power are significant. However, in terms of the CDM the question is whether gas can be considered 'additional' in South Africa, or whether it would happen for commercial reasons. The broader debate is whether the CDM should be a means to promote gas, given its lower carbon intensity, or whether scarce CDM investment should go to projects which are not financially viable at current prices.

---

13 The fuel-specific comparison does not apply, since no fuel is consumed in the sense that fossil fuels are used.

Table 6. Energy intensity (MJ/kWh) and carbon intensity (kg C/kWh) per CDM project

	New gas: Cape Power Project	Wind energy: Darling	New coal: supercritical steam	Efficient Lighting Initiative	Off-grid solar home systems
Energy intensity	6.546	n/a	7.660	n/a	n/a
Carbon intensity	0.100	0.000	0.216	0.000	0.000

Table 7. Decrease in carbon intensity from CDM project against NEAR FUTURE baseline (kg C/kWh)

	Baseline standard	New gas: Cape Power Project	Wind energy: Darling	New coal: Super-critical steam	Efficient Lighting Initiative	Off-grid Solar Home Systems
Fuel specific	Weighted average	0.000	n/a	0.101	n/a	n/a
	25th percentile	0.000	n/a	0.079	n/a	n/a
	10th percentile	0.000	n/a	0.079	n/a	n/a
	Best plant	0.000	n/a	0.079	n/a	n/a
All fossil	Weighted average	0.170	0.270	0.054	0.270	0.270
	25th percentile	0.028	0.128	-0.088	0.128	0.128
	10th percentile	0.000	0.100	-0.116	0.100	0.100
	Best plant	0.000	0.100	-0.116	0.100	0.100
Sector wide	Weighted average	0.147	0.247	0.031	0.247	0.247
	25th percentile	-0.035	0.065	-0.150	0.065	0.065
	10th percentile	-0.087	0.013	-0.203	0.013	0.013
	Best plant	-0.100	0.000	-0.216	0.000	0.000

In the South African context, the sector-wide baseline appears to make the most sense, because the actual electricity displaced by these projects will include the coal, gas and hydro-power that would likely come on-line from 2000 to 2005. The CDM projects will not only displace coal power, so that any fossil-fuel projects that want to attract CDM investment have to compete with gas and hydro, as do renewables.

This approach assumes that one is aiming to ensure environmental integrity – that is, that any emissions reductions claimed are real. If the aim were to maximise the number of CERs produced in South Africa, that would imply a different set of choices.

5.2 Comparing 'near future' to 'recent plant' baselines

If the baseline is taken to include the only recent plant (the four Majuba units commissioned from 1996 – 1999), then the carbon intensities are different from the near future baseline. The performance of the CDM projects remains the same, but they are compared to a different baseline of a recent plant.

One should note that, while there are six Majuba units, they are really two sets of three identical units (for the purposes of this analysis). The first three units are dry-cooled and thus assumed to have a slightly lower thermal efficiency (but better water-use efficiency), while unit 4 is wet-cooled (as are units 5 and 6, to be commissioned 2000 - 2001. Given only two sets of units, the values for the 25th percentile, 10th percentile and best plant are the same, as evident in Table 8.

Table 8. Decrease in carbon intensity from CDM project against RECENT PLANT baseline (kg C/kWh)

	Baseline standard	New gas: Cape Power Project	Wind energy: Darling	New coal: super-critical steam	Efficient Lighting Initiative	Off-grid solar home systems
Fuel specific	Weighted average	n/a	n/a	0.085	n/a	n/a
	25th percentile	n/a	n/a	0.079	n/a	n/a
	10th percentile	n/a	n/a	0.079	n/a	n/a
	Best plant	n/a	n/a	0.079	n/a	n/a
All fossil	Weighted average	0.201	0.301	0.085	0.301	0.301
	25th percentile	0.194	0.295	0.079	0.295	0.295
	10th percentile	0.194	0.295	0.079	0.295	0.295
	Best plant	0.194	0.295	0.079	0.295	0.295
Sector wide	Weighted average	0.201	0.301	0.085	0.301	0.301
	25th percentile	0.194	0.295	0.079	0.295	0.295
	10th percentile	0.194	0.295	0.079	0.295	0.295
	Best plant	0.194	0.295	0.079	0.295	0.295

A comparison between the harder *near future* baseline and the less stringent *recent plant* baseline in Table 8 shows the following:

- CDM projects generally do better with the *recent plant* reference scenario, since the baseline is 'easier to beat', especially in the sector-wide comparison, since this now only includes coal.
- Renewables show small increases, particularly for the weighted average of all fossil-fuel plants; and in all baselines of the sector-wide comparison.
- New coal does better for the weighted average, fuel-specific comparison – this is because the near future baseline includes bringing back moth-balled coal-fired plants, with lower assumed efficiencies. The only recent plant is Majuba, with four units commissioned to date. However, once one expands the comparison to 'all fossil' for the 10th percentile and best plant, new coal switches from negative to positive – that is, against the near future

baseline, there would be no project, while the recent plant baseline would accept this for the CDM. This is due to the inclusion of gas in the near future baseline. Sector-wide, the same switch occurs even for the 25th percentile, as now gas and hydro come into play.

The implications of using 'recent plant' in South Africa is to allow credits that probably overstate the 'real' reductions, given the changes expected in the industry. These results support our argument that for South Africa, a baseline looking at near future plants is more effective in ensuring environmental integrity. The additional credits from a less stringent baseline can be quite substantial, as shown in the annual emissions reductions in kilotons of carbon in Table 9. These tables reflect the different size of projects, as well as their carbon intensity.

Table 9. Carbon reductions by project based on NEAR FUTURE baseline (kilotons C/yr)

	Baseline standard	New gas: Cape Power Project	Wind energy: Darling	New coal: supercritical steam	Efficient Lighting Initiative	Off-grid solar home systems
Fuel Specific	Weighted average	none	N/a	1,053	N/a	N/a
	25th percentile	none	N/a	824	N/a	N/a
	10th percentile	none	N/a	824	N/a	N/a
	Best plant	none	N/a	824	N/a	N/a
All fossil	Weighted average	351	2	569	1,081	7
	25th percentile	58	1	none	513	3
	10th percentile	0	1	none	401	3
	Best plant	none	1	none	401	3
Sector wide	Weighted average	303	2	324	987	6
	25th percentile	none	1	none	262	2
	10th percentile	none	0	none	53	0
	Best plant	none	none	none	none	none

Of note in these results are the relatively small absolute carbon reductions for the wind energy and off-grid SHS projects. For wind, this is primarily due to the small size of the project (5 MW). Given the good performance of wind on carbon intensity, this points to the need to scale up renewable energy projects.

If better-than-average benchmarks (e.g. 25th percentile) are applied, the fossil-fuel CDM projects analysed result in no or relatively small carbon reduction for their size. If one wanted to choose between projects, further analysis would need to take into account both the size of projects and the cost of reduction ($/tC).

The carbon reductions were also compared given the recent plant reference scenario. The results are shown in Table 10. Given a 'softer' baseline based on the recent plant, the carbon reductions are generally higher. If, however, a stricter baseline is applied, these emissions would not be credited.

Table 10. Carbon reductions by project based on RECENT PLANT baseline (kilotons C/yr)

	Baseline standard	New gas: Cape Power Project	Wind energy: Darling	New coal: supercritical steam	Efficient Lighting Initiative	Off-grid solar home systems
Fuel specific	Weighted average	N/a	N/a	892	N/a	N/a
	25th percentile	N/a	N/a	824	N/a	N/a
	10th percentile	N/a	N/a	824	N/a	N/a
	Best plant	N/a	N/a	824	N/a	N/a
All fossil	Weighted average	415	3	892	1 204	8
	25th percentile	402	3	824	1 178	8
	10th percentile	402	3	824	1 178	8
	Best plant	402	3	824	1 178	8
Sector wide	Weighted average	415	3	892	1 204	8
	25th percentile	402	3	824	1 178	8
	10th percentile	402	3	824	1 178	8
	Best plant	402	3	824	1 178	8

5.3 Comparing projects against multi-project and project-specific baselines

Can one compare these results to those from project-based baselines? No complete analysis has been done in this paper, but some illustrative example raise further research issues. One available project-specific analysis is for off-grid solar home systems in a rural concession area (50 000 households). The study found a total of 11 500 tons of avoided CO_2 emissions per annum (Wamukonya & Tyani 1999: 3). Converting to the same target market and to carbon, the equivalent reduction calculated by project-based baseline is 22 kilotons of carbon per year. Under the near future baseline, the range is from 0 to 7 kilotons carbon per year. However, this comparison does not compare equal quantities, in that the multi-project baseline implicitly assumes that electricity is avoided. In reality, rural South African households would tend to use paraffin or candles for lighting (Wamukonya & Tyani 1999). The comparison between project-specific and multi-project baselines requires further analysis.

Another example is an analysis of efficient lighting (Spalding-Fecher *et al* 1999). Converting to equivalent number of compact fluorescent lightbulbs, the study found that 360 ktC/year would be avoided. This is within the range of results in Table 9, from zero to 1 081 ktC, depending on which comparison set and benchmark is used. The fact that this is in the low range is due to different assumptions – the study assumed 3.2 hours of lighting per day, while six hours were used in the present analysis.

The conclusion from these two examples is that assumptions remain critical. Multi-project baselines, being standardised, can conflate many assumptions in a single number. While that single number provides certainty about the benchmark, subjective elements will always remain in gathering information about the CDM project. So multi-project baselines cannot eliminate all subjectivity from the overall process of determining additionality and calculating CERs.

5.4 Avoided emissions

An issue that has not been dealt with thus far is whether baselines deal only with reducing current emissions, or also with avoiding future emissions. Sokona *et al* argue that an exclusive emphasis on emissions reductions disadvantages least developed countries (LDCs), including many African countries. Emissions in these countries can be expected to grow, perhaps even with CDM projects. These countries will be excluded from the CDM 'unless equal attention is given to the possibility of avoiding future emissions through CDM projects in these countries. Avoidance of future emissions matches both the demand of sustainable development and the overall objectives of the Convention' (Sokona, Humphreys & Thomas in Goldemberg 1998: 111). Rather than reducing historical emissions, development paths that avoid emissions *in the future* should be assisted. Allowance should therefore be made for *avoided future emissions*, which is acknowledged in sections of the current negotiating text (UNFCCC 2000: § 64): 'The baseline may include a scenario where future anthropogenic GHG emissions … are projected to rise above current levels, due to the specific circumstances of the host party'.

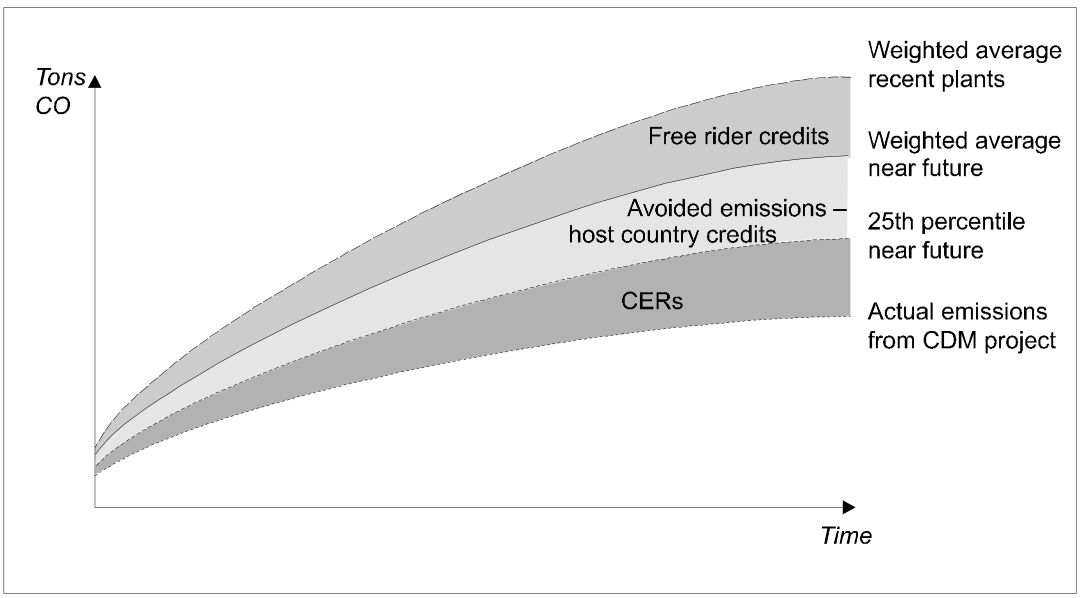

Figure 6. CERs, host country and free-rider credits under different baselines

How can avoided emissions be built into the analysis of baselines? Because this analysis uses a forward-looking baseline, all the reductions from a weighted average near future are our best estimate of the potential future emissions reduction from the CDM project. However, given the uncertainty in baselines, the need to ensure the environmental integrity of the Protocol (particularly during the first commitment period) by minimising free riders,[14] and the importance of ensuring the CDM projects bring cutting edge technology, it makes more sense to only award CERs for some portion of this 'best estimate' of emissions reduction.

Our proposal, therefore, would be to use the better-than-average baseline (in this case 25th percentile performance) for the calculation of CERs, but for the host country to receive credits for the avoided emissions between the better-than-average and weighted average baselines. As long

14 Free riders in economic theory are those who benefit from a public good without paying for it. In this case, free riders receive CERs for a business-as-usual project, even though they incurred no additional cost.

as these credits were not used during the first commitment period, they would not affect the environmental integrity of the Kyoto Protocol. If non-Annex I countries instead bank the credits, this gives them a real stake in emissions reductions. This is illustrated in Figure 6 which compares the areas representing the CERs, avoided emissions credits received by the host country, and free rider credits. Note that if the baseline were set using a backward-looking average of recent plants, this could increase the amount of free rider credits significantly. This is a key reason why using a backward-looking baseline to calculated CERs in South Africa is not recommended.

A possible objection against crediting developing countries with 'avoided emissions' credits is that they may reduce CDM investment (since the benefits returning to investors are diminished). Clearly further research is needed on including avoided emissions in baselines.

6. Conclusion

6.1 'Near future' baseline appropriate for South Africa

The analysis of multi-project baselines for the power generation sector suggests that a backward-looking baseline looking at recent plants is not appropriate in South Africa, because of the small number of recent plants and changes in new, marginal plants. A comparison to recent plants could work in countries where many plants have been constructed, at the margin, in recent years. This is not the case in South Africa, although it may well be true of other developing countries.

Using a 'near future' baseline represents our best estimate of what is likely to happen in the South African power sector. Our analysis is based on the assumption that a separate additionality test would screen out projects that do not meet environmental, financial, investment and technological additionality (UNFCCC 2000). In this case, the danger that a weighted average 'near future' baseline would 'simply be built' and give away many free-rider credits is avoided – such projects are screened out through the additionality test.

If 'recent plant' were to be used in South Africa, one would need to go back some 20 years or so to get a reasonably representative baseline. That would defeat the purpose of 'recent plant' baselines, which is to include marginal, relatively efficient technologies. Any backward-looking baseline, would have to adjust its analysis to take into account technological change – through a factor for autonomous increases in energy efficiency, for example.

Alternatively, if one wanted an observable baseline, one might extend the analysis to a broader region, to include a sufficient number and diversity of recent plants. Regional analysis makes sense where there are grid connections and trading. Future research could look at such an analysis for the Southern African Development Community. For this analysis, we have chosen a baselines looking at six 'near future' plants and units. Since these are future plants, the baseline itself is a projection, determined by the underlying assumptions.

6.2 Balancing investment and environmental integrity

Baselines need to strike a balance between ensuring environmental integrity and attracting CDM investment. Baselines should minimise transaction costs and maximise the number of projects. Two options might be followed by South Africa – to choose a single baseline, or to use different baselines for different projects.

6.2.1 Option A: Choosing a single baseline

Comparing the increasingly strict benchmarks ranging from weighted average, 25th percentile, 10th percentile and best plant. The weighted average, being the 'softest' baseline, allows the largest number of CDM projects to qualify and does reflect the projected mix of the sector. The best plant and 10th percentile benchmarks appear overly restrictive, in that even renewable energy projects show only a marginal improvement in carbon intensity.

The 25th percentile benchmark is an intermediate choice and would still help to provide incentives to introduce advanced technologies. Being a better-than-average benchmark, it reduces the opportunities for free-riders to gain credits. In the 'all fossil' comparison, it allows five projects to qualify. If the comparison is extended to the whole sector, new coal and new gas are excluded.

In the South African context, the sector-wide baseline appears to make the most sense, because the actual electricity displaced by these projects will include the coal, gas and hydro-power that would likely come on line from 2000 to 2005. A single sector-wide benchmark provides a strong incentive to invest in low-carbon technologies. The CDM projects will not only displace coal power. Hence any fossil-fuel projects that want to attract CDM investment have to compete with gas and hydro, as do renewables. More efficient coal plants could still be developed if a weighted average benchmark is used, but the emissions reductions would be relatively small. The crediting of avoided emissions may be a mechanism for assigning some emissions reductions to host countries.

While the purpose of the analysis is to compare baselines, rather than potential CDM projects, we cannot avoid the issue of fossil-fuel CDM projects. New coal would only be eligible under less stringent baselines. The analysis also highlights the debate whether gas can be considered additional in the South African context. This debate turns not so much on technical assessment of carbon intensity, but an assessment of what is financially viable in South Africa currently.

One option for South Africa, based on the analysis in this paper, with all its assumptions, would be to use a sector-wide, 25th percentile baseline for all CDM projects in the electricity generation sector. Another option is to choose different baselines for CDM projects with different attributes.

6.2.2 Option B: Different baselines for different projects

Different CDM projects have specific attributes, and so might be measured against different baselines. One approach is to match projects with the load profile that they would displace. A new super-critical coal plant would be used for baseload, displacing other coal plants. Large new gas plants are also likely to be used for baseload, but can be brought on-line more quickly and hence used for peaking power. Energy efficiency projects displace some average of electricity generation, so that perhaps a weighted average would be appropriate.

Differentiating baselines would allow the test for additionality to be separated from the calculation of CERs. This may be useful, for example, for small-scale renewables and energy efficiency projects. In terms of additionality, these projects could simply be accepted, while their CERs could be calculated against a sector-wide baseline. New coal and gas, by contrast, can be expected to meet a stringent additionality test to qualify for CDM investment, e.g. 10th percentile. However, once such projects have been approved, calculating CERs from a 25th percentile benchmark would make them more attractive to investors, and would also allow some credits to be assigned to the host country.

For this analysis, not enough information was available to explore all the implications of this approach. Further work is required, given that the reference scenario only includes a few near future plants, while load profile are defined in relation to the entire sector, including older plants. On the basis of available information, one might therefore compare new coal and gas to the all-fossil baseline, but use the sector-wide comparison for energy efficiency.

6.3 Choices for South Africa

The advantage of a single baseline is that it is simple, and treats all technologies equally. For the electricity sector, it can include both supply and demand side options. The attraction of different baselines for different CDM projects is that they can more accurately reflect what the project displaces. A single benchmark for the electricity sector is attractively simple. A project-specific approach promises more accuracy in 'getting the reductions right', but has higher costs.

This analysis provides initial thoughts towards constructing such baselines. Hopefully it has made a small contribution to outlining possible policy options for South Africa and their implications. A final decision will require further research and a consultative process of decision-making. Particular areas that require further attention include:

- extending the analysis from South Africa to the entire Southern African Development Community;
- more detailed comparison of multi-project against project-specific baseline, applied to specific projects, which may require additional project-specific studies;
- introducing some dynamics over time to the static analysis presented here;
- considering different types of power stations being displaced, e.g. base-load and peak-load;
- improving data quality, such as coal consumption per power station or unit; and
- considering individual units within power stations, where they differ significantly from one another.

Such research would place South Africa in a better position to choose a baseline methodology. In doing so, it will need to strike a balance between maximising the number of CDM projects and minimising transaction costs on the one hand, and allowing free-riders in the CDM, threatening environmental integrity.

Acknowledgement

This paper contributes to a larger research effort co-ordinated by the Lawrence Berkeley National Laboratory (LBNL). Similar studies are also being conducted in Brazil, India and China. LBNL is supporting the presentation of the results of this paper to the sixth Conference of the Parties (COP-6) to the UN Framework Convention on Climate Change, held in The Hague, Netherlands from 13 – 25 November 2000.

The views expressed in this paper are solely those of the authors, and do not claim to represent the position of the South African government, nor the views of utilities or any other stakeholders. While use has been made of input from government and utility sources, any errors are the responsibility of the authors.

References

Asamoah, J, 2000. Darling demonstrates the power of wind, *African Energy Journal*, 2(4): 32-35.

Cooper, CJ, 1997. South African energy balances for 1997. Department of Minerals and Energy, Pretoria.

Department of Minerals and Energy (DME), 1996. Energy in South Africa, DME, Pretoria.

Department of Minerals and Energy (DME) 1998. White Paper on Energy Policy for South Africa.

Department of Minerals and Energy (DME) 2000. Energy Balances for South Africa 1993-98. Microsoft Excel Spreadsheets. Unpublished. Pretoria.

Eskom, 1996. *Statistical yearbook.* Electricity Supply Commission, Johannesburg.

Eskom, 1998a. *IEP6: Integrated electricity plan for the period 1997 – 2016*. Eskom, Johannesburg.

Eskom 1998b. *Environmental report 1997*. Eskom, Johannesburg.

Eskom, 1999. *Annual report 1998*. Eskom, Johannesburg.

Eskom, 2000. Efficient lighting initiative. Eskom, Johannesburg.

Goldemberg, Jose (ed.), 1998. *Issues and options: The Clean Development Mechanism.* United Nations Development Programme, New York.

Grubb, Michael, 1999. The Kyoto Protocol: A guide and assessment. Royal Institute of International Affairs, London.

Howells, Mark, 1999. Baseline and greenhouse gas mitigation options for bulk energy supply, South African Country Study on Climate Change. Draft. Energy Research Institute, University of Cape Town.

International Energy Agency (IEA), 2000. *Key world energy statistics 2000 edition*.

Intergovernmental Panel on Climate Change (IPCC), 1995. *Greenhouse gas inventory workbook.* Vol. 2. UNEP, OECD, IEA and IPCC, London.

Karottki, R & Banks, D, 2000. Power and profit? Electrifying rural South Africa, *Renewable energy world,* Jan 2000: 51-59.

Lazarus, M, Kartha, S, Ruth, M, Bernow, S & Dunmire, C 1999. Evaluation of benchmarking as an approach for establishing Clean Development Mechanism baselines. Tellus Institute, Boston.

Meyers, S, 2000. Determining baselines and additionality for the Clean Development Mechanism: Are simplified methods viable? Lawrence Berkeley National Laboratory.

National Electricity Regulator (NER), 1999. *Electricity supply statistics for South Africa.* NER, Johannesburg.

Natural Resources Defense Council (NRDC) & Public Service Electric and Gas (PSEG), 1998. Estimated electric sector CO_2 emission rates by country. Mimeo.

Praetorius, B & Spalding-Fecher, R 1998. Greenhouse gas impacts of DSM: Emission reduction through energy efficiency interventions in low-income urban households. Energy & Development Research Centre, University of Cape Town.

Qase, N, 2000. Too little too late: Understanding rural community reactions to solar home systems in South Africa. Paper presented East African Power Industry Convention, Kampala, 16-19 October 2000.

Roggen, W, 2000. Personal communication. (Athlone Power Station Manager).

Scholes, RJ & Van der Merwe, MR, 1995. South African greenhouse gas inventory (Report DEA-918). Pretoria. Centre for Scientific and Industrial Research, Division of Forest Science and Technology, Pretoria.

Spalding-Fecher, R, Clark, A, Davis, M & Simmonds, G, 1999. Energy efficiency for the urban poor: economics, environmental impacts and policy implications. Energy & Development Research Centre, University of Cape Town.

Trollip, H, 1996. Overview of the South African energy sector. Report no. EG9404. Pretoria: Department of Minerals and Energy.

United Nations Framework Convention on Climate Change (UNFCCC), 2000. Mechanisms pursuant to Articles 6, 12 And 17 of the Kyoto Protocol: Text by the chairmen: Addendum: Article 12 of the Kyoto Protocol UNFCCC document FCCC/SB/2000/Add.2.

UNFCCC, 1992. United Nations Framework Convention on Climate Change.

UNFCCC, 1997. Kyoto Protocol to the United Nations Framework Convention on Climate Change, document FCCC/CP/1997/7/Add.1

Wamukonya, N & Tyani, L, 1999. Solar home systems as a CDM project: A hypothetical case study. Paper presented to the Domestic Use of Electrical Energy Conference, Cape Town.

World Commission on Dams (WCD), 2000. Dams and global change. WCD Thematic Review, Cape Town.